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EDIN DESIGN STUDY ALTERNATE SPACE SHUTTLE BOOSTER REPLACEMENT CONCEPTS

VOLUME I - ENGINEERING ANALYSIS

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FOREWORD

This report is a technical assessment of a Shuttle-based launch system consisting of the Shuttle Orbiter, the external tank, and a recoverable liquid rocket booster system replacing the solid rocket booster system. This report was prepared for Johnson Space Center under Contract NAS9-14520. This study was conducted under the direction of Mr. Robert W. Abel, the technical monitor and H. P. Davis, chief of the Future Programs Office.

Compilation and publi·ation of this assessment involved the time, effort and cooperation of a number of organizations and individuals. NASA personnel directed the study and defined design requirements and constraints. The actual computations and the majority of analysis used to generate the report were provided by the Sigma Corporation. Willie E. Heineman of EW2 checked vehicle weights and provided a number of the weight algorithms.

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INTRODUCTION

The use of a recoverable liquid rocket booster (LRB) system to replace the existing solid rocket booster (SRB) system for the Shuttle offers the potential of extending the payload capability and of cost saving by recovery and re-use of the LRB with a minimum of refurbishment cost. The concept uses the basic Orbiter modified to include a weight penalty to account for the additional structure necessary to accommodate the increased payload and the Shuttle ET modified to account for deletion of the SRB/ET attachments and scaled according to a constant mass fraction. Some modification of the ET would be required to take thrust loads longitudinally along the tank rather than laterally through the tank. Two different types of LRB were investigated. One consisted of three and four up-rated F-1 engines, while the other was powered by high-pressure LOX/RP engines based on those proposed by Mr. Rudi Beichel of Systems Development Corporation. The LRB is mounted aft of the ET and is jettisoned at booster engine cut-off (BECO) and recovered for re-use.

The present study, designated EDIN05, was initiated for the purpose of assessing this LRB concept. The study, based on information contained in References 1 through 6, was performed using EDIN software and hardware and represents a joint effort between NASA and Sigma Corporation. The NASA Engineering Analysis Division and the Future Programs Office were involved in defining design requirements and constraints. Sigma Corporation developed the simulation procedures and supported the engineering analysis and computations.

Historical weight estimating relationships were developed for the LRB using Saturn technology and modified as required to support the EDIN05 study. Mission performance was computed using February 1975 Shuttle configuration groundrules to allow reasonable comparison of the existing Shuttle with the EDIN05 designs. The launch trajectory was constrained to pass through both the RTLS/AOA and main engine cut-off (MECO) points of the Shuttle Reference Mission 1. Performance analysis is based on a point design trajectory model which optimizes initial tilt rate and exo-atmospheric pitch profile. A gravity turn was employed during the boost phase in place of the Shuttle angle-of-attack profile. Engine throttling add/or shutdown was used to constrain dynamic pressure and/or longitudinal acceleration where necessary. Four basic configurations were investigated: a parallel-burn vehicle with an F-1 engine-powered LRB; a parallel-burn vehicle with a high-pressure engine-powered LRB; a series-burn vehicle with

a high-pressure engine-powered LRB. The relative sizes of the LRB and the ET are optimized to minimize GLOW in most cases.

This report comprises two volumes. Volume I contains an engineering analysis of each simulation performed, a description of the simulation programs and procedures, and a discussion of the LRB weight estimating relationships. Volume II presents the detailed results of the simulations, including weight statements, trajectory plots, and mass properties breakdowns.

STUDY GUIDELINES AND ASSUMPTIONS

Concept

The basic purpose of the EDIN05 study series was the conceptual design of several Space Shuttle configurations in which the solid rocket boosters (SRB's) were replaced by a recoverable liquid rocket booster (LRB), and the external tank (ET) was resized to satisfy performance requirements. This concept is illustrated in figure 1.

Mission

The design mission for the studies was the Space Shuttle Reference Mission 1, modified to achieve a greater payload. This mission consists of a due east launch from the Eastern Test Range (ETR) into a 50x100 nautical mile orbit with an inclination of 28.5 degrees. The launch trajectory was constrainted to pass through both the Return to Launch Site/Abort Once Around (RTLS/AOA) and Main Engine Cutoff (MECO) points of the Shuttle Reference Mission 1. These points were defined by inertial velocity, inertial gamma and altitude as follows:

Nominal Mission 1	Velocity (ft/sec)	Gamma (deg)	Altitude (ft)
RTLS/AOA	9492	7.09	348,566
MECO	25,665	0.50	394,341

The basic EDIN05 mission is illustrated in figure 2.

Performance

The initial tilt rate and exo-atmospheric pitch profile were optimized to obtain the trajectory for maximum payload or minimum gross lift-off weight (GLOW) in each study case. The trajectories employed a gravity turn from end of tilt to booster engine cut-off (BECO) and were constrained to prohibit dynamic pressure in excess of 650 psf and longitudinal acceleration in excess of 3.0g by engine throttling and/or shutdown.

Propulsion

Four types of engines were used in the various EDIN05 propulsion systems: The Space Shuttle Main Engine (SSME), the F-1 and two versions of the high chamber-pressure engine proposed by Beichel, one rated at 680,000 lb. sea-level thrust

ORBITER

- FEBRUARY 1975 SHUTTLE ORBITER
- MODIFIED FOR INCREASED UP-PAYLOAD

EXTERNAL TANK

- RESIZED FOR INCREASED PAYLOAD AND MINIMUM GLOW
- STRUCTURAL MODIFICATIONS FOR LIQUID
- ROCKET BOOSTER

LIQUID ROCKET BOOSTER

- BASED ON SATURN TECHNOLOGY
- USES EXISTING F-1 ENGINES OR HI-PC ENGINES
- SIZED FOR MINIMUM GLOW

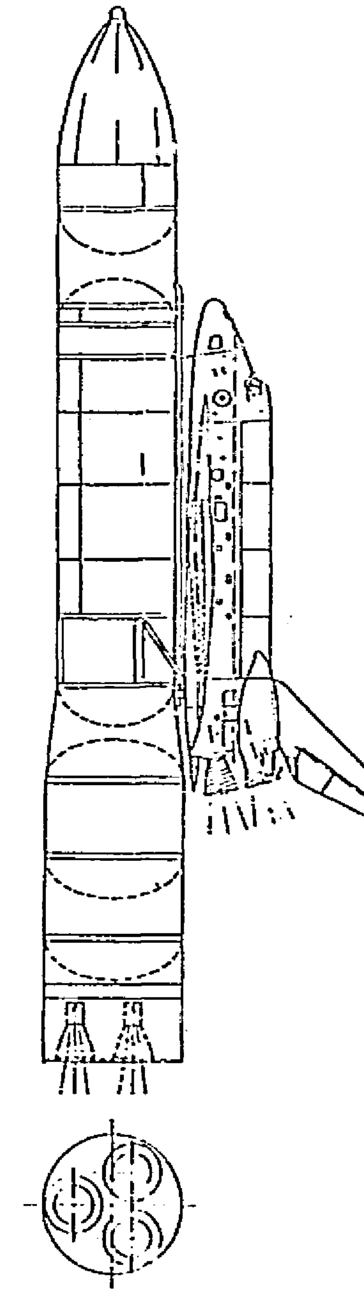


FIGURE 1   EDIN05 SRB REPLACEMENT STUDY

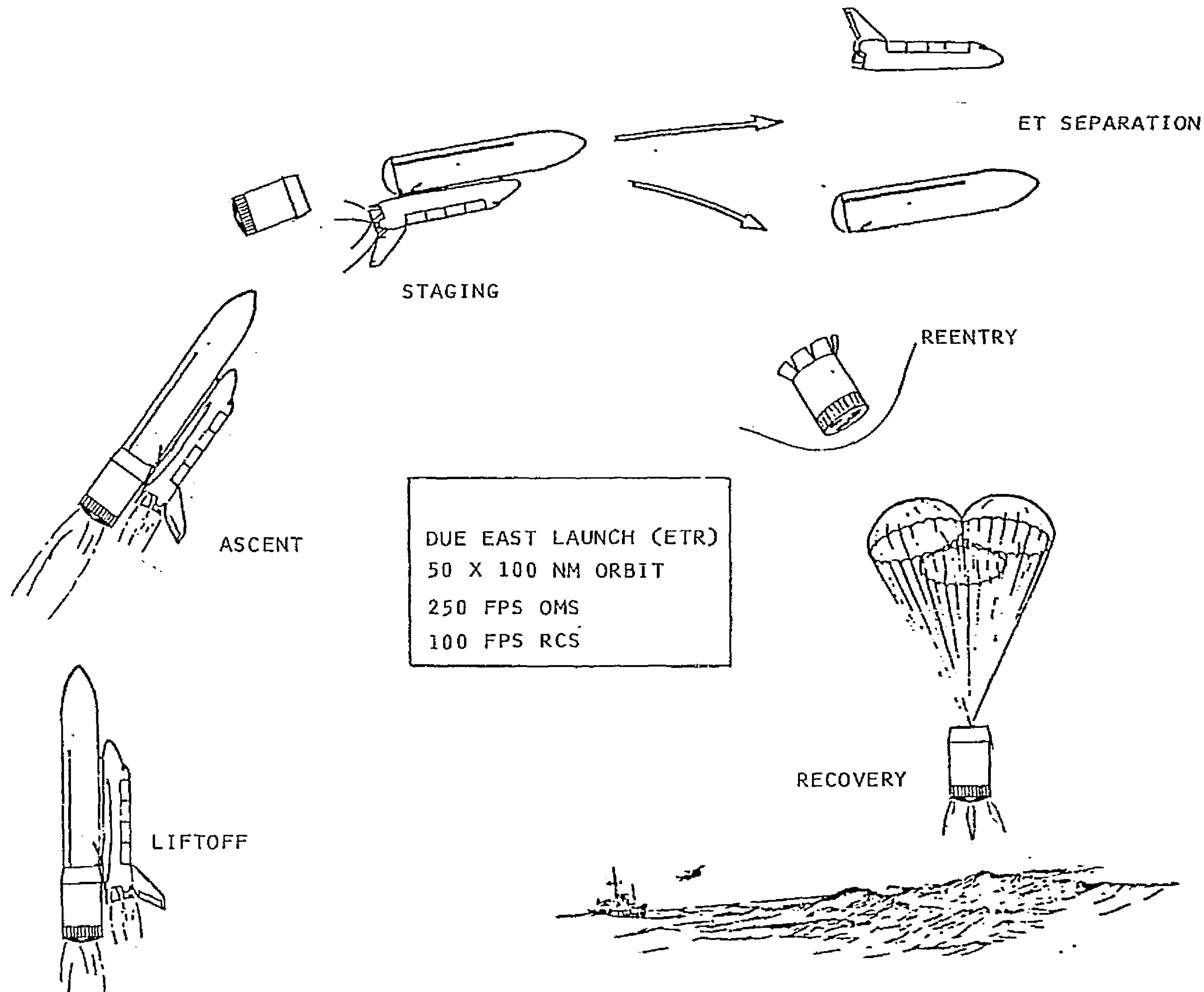


FIGURE 2 EDIN05 DESIGN MISSION.

nd the other rated at 800,000 lb. sea-level thrust. Furthermore, the 800,000 lb. sea-level thrust high-pressure engines were operated at two different mixture ratios. In the F-1 powered configurations, the dynamic pressure and longitudinal acceleration were constrained, if necessary, by SSME throttling or, in the event that maximum throttling was not sufficient to limit dynamic pressure or acceleration, by shutting down an F-1 engine. In the high-pressure engine-powered configurations, these constraints were met, if necessary, by high-pressure engine throttling (prior to BECO) and SSME throttling (post-BECO). The propulsion data used in this study is presented in figure 3.

Aerodynamics

Aerodynamics data for launch performance optimization were obtained from Shuttle aerodynamics estimates. The reference area was adjusted to account for replacement of the SRB's by a 33 foot diameter LRB. A plot of base drag vs. altitude is included as figure 4.

Structure

The Orbiter structural weight was modified to account for the additional structure necessary to accommodate the increased up payload. The ET structural weight was modified to account for the deletion of the SRM/ET attachments. The LRB stage is illustrated in figures 5 and 6. The tanks are nested to minimize intertank length. Insulation is provided to reduce thermal effects. The interstage structure between the ET and the LRB contains the recovery equipment and the structure and controls for the aerodynamic stabilization (reentry) system. The LOX is transferred through the RP tank by three feed lines. A retro system is housed within the aft skirt to decelerate the reentered stage just prior to water impact. An ablative heat shield is provided on the upper portion of the tank system to protect the tank from SSME plume impingement.

Mass Properties

The Orbiter mass properties are those for the February 1975 Orbiter, modified to account for the increased payload. The ET mass properties are based upon a fixed mass fraction with weights distributed according to the Shuttle ET weight statement. The LRB mass properties were obtained from weight estimating relationships based on Saturn technology.

The LRB and ET mass properties were calculated by the program WAB. WAB considers all the components of each subsystem as black boxes and uses the parallel-axis theorem to sum the individual masses, x-cg distances and moments of inertia.

CHARACTERISTIC	SPACE SHUTTLE MAIN ENGINES (SSME'S)	F-1'S	680K HIGH-PRESSURE	800 HIGH-PRESSURE	
Configuration	All	EDIN0501 EDIN0504B EDIN0504D EDIN0505	EDIN0502A EDIN0502B	EDIN0503 EDIN0504	EDIN0504A EDIN0504C
Sea-Level Thrust/Engine (Lb.)	375,000	1,606,788.5	680,000	800,000	800,000
Vacuum Thrust/Engine (Lb.)	470,000	1,748,060	735,300	856,800	866,293
Sea-Level Specific Impulse (Sec.)	363.2	266.01	319.6	327.6	321.0
Vacuum Specific Impulse (Sec.)	455.2	289.4	345.6	350.8	347.6
Propellant Flow Rate (Lb./Sec.)	1032.5	6040.2	2127.7	2442.2	2492.2
Engine Throttling	109% to 50%	N/A	100% to 50%	100% to 50%	100% to 50%
Exit Area/Engine ($Ft.^2$)	44.896	66.763	27.122	31.73	32.00
Mixture Ratio	6	2.27	2.4	2.9	2.5
Fuel	LH2	RP-1	RP-1	RP-1	RP-1
Oxidizer	LOX	LOX	LOX	LOX	LOX

FIGURE 3 EDIN05 PROPULSION DATA.

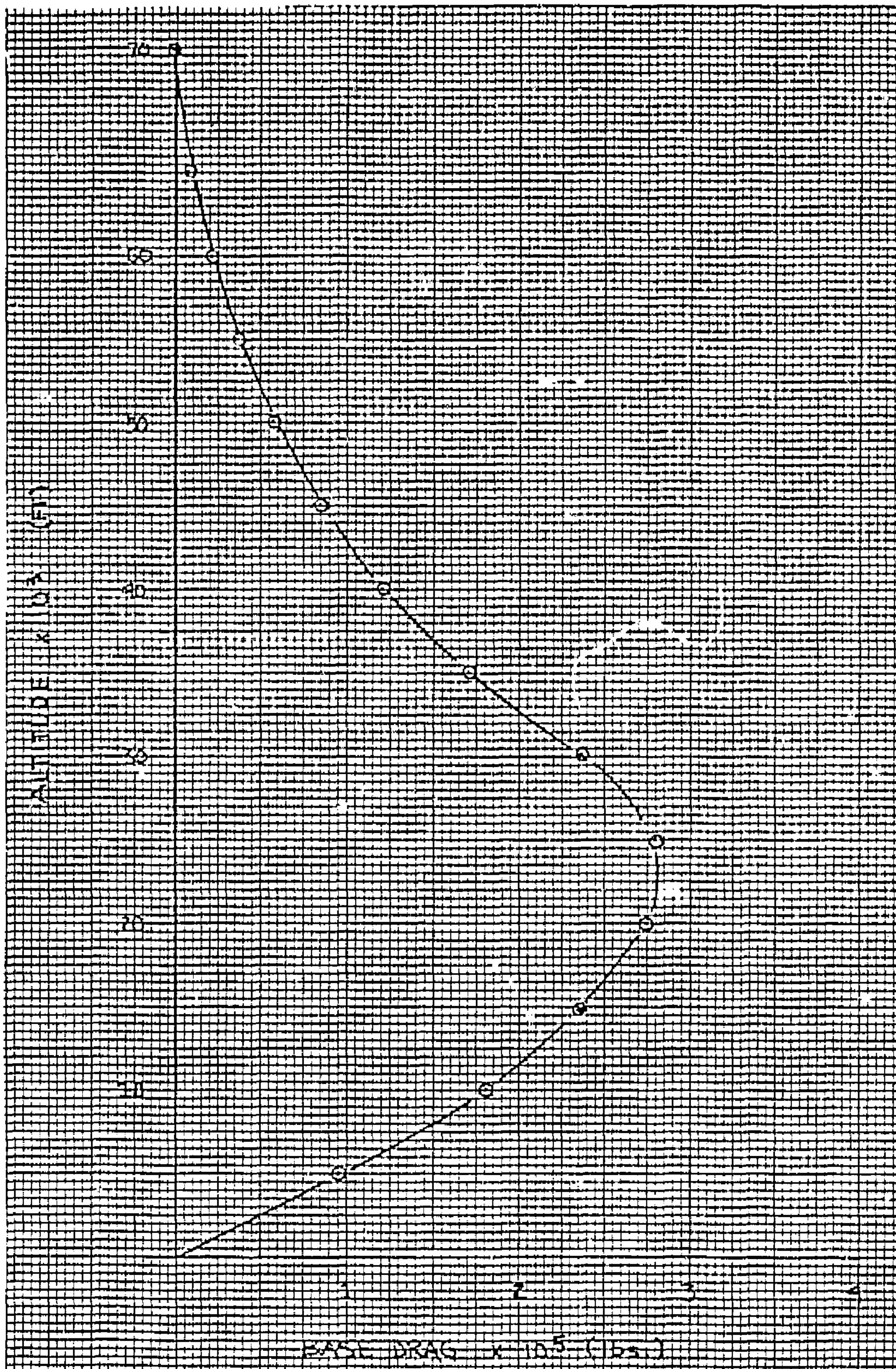


FIGURE 4 - BASE DRAG VS ALTITUDE.

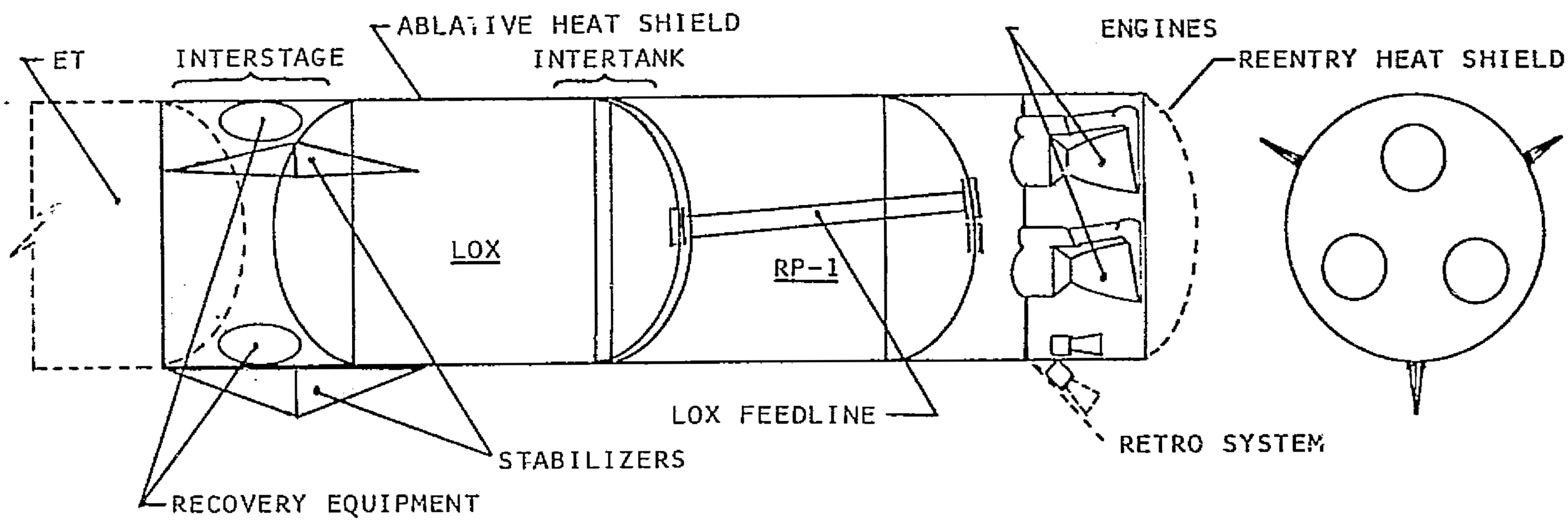


FIGURE , 5 LIQUID ROCKET BOOSTER REPLACEMENT FOR SHUTTLE SRB.

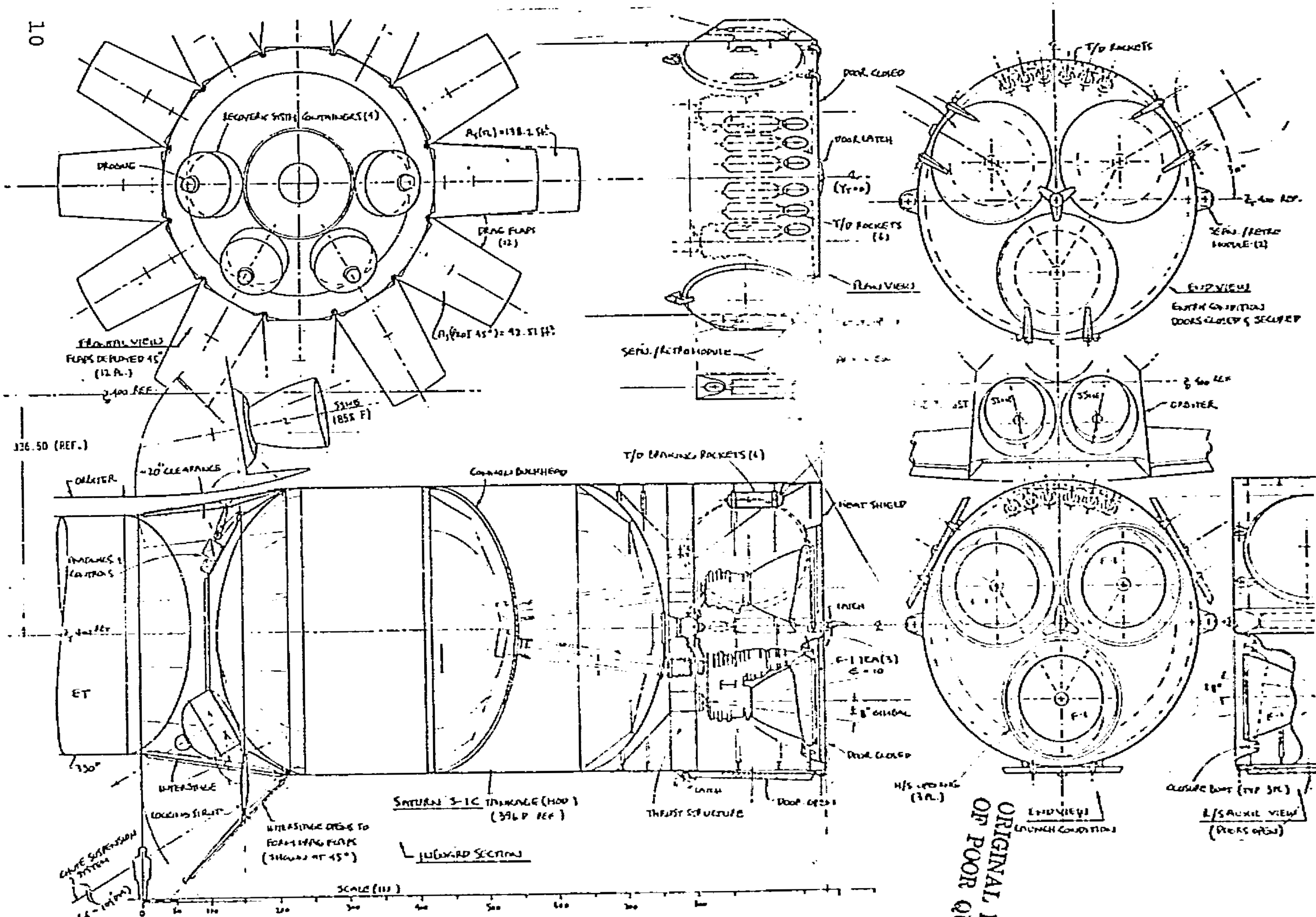


FIGURE 6 LIQUID ROCKET BOOSTER GEOMETRY

The masses used for the components were those generated in the weight statements. The length of each component was calculated in WAB and the x-cg positions were then calculated under the assumption that each component was homogeneous. WAB calculated moments of inertia for the LRB and ET by assuming general geometric shapes for their major components and then calculating and summing their individual inertias.

SIMULATION DESCRIPTION

Programs

The major programs used in the EDIN05 simulations were SIZER, PROP, WTORB, ETWT, LRBWT, SEMF, ROBOT and CONVG.

SIZER. - SIZER uses the ideal rocket equation:

$$V_I = I_s g \ln \frac{W_I}{W_F}$$

to calculate stage propellant weights and uses input mass fractions to calculate gross stage weights from the stage propellant weights. In the parallel burn cases, since the LRB and the SSME's burn simultaneously over a portion of the trajectory, a true mass fraction cannot be determined for each stage. Hence, for the parallel burn cases, the mass fractions employed in the preliminary sizing were effective mass fractions which were determined by the following formulas:

$$\lambda_1' = \frac{W_{P_1}}{W_{P_i} + W_{I_{LRB}}} \quad ; \quad \lambda_2' = \frac{W_{P_2}}{W_{P_2} + W_{I_{ET}}}$$

where W_{P_i} is the weight of propellant burned in the ith stage, and $W_{I_{LRB}}$ and $W_{I_{ET}}$ are the inert weights of the LRB and the ET, respectively.

PROP. - PROP distributes the propellant allocated by SIZER between the LRB and the ET. For the F-1 engine-powered configurations, the LRB burns in two distinct phases, which are separated by the point at which one F-1 engine is shut down to limit dynamic pressure or longitudinal acceleration. The LRB propellant is thus given by:

$$W_P = N\dot{W}_{F-1}t_1 + (N-1)\dot{W}_{F-1}t_2$$

where N is the number of LRB engines, $\dot{W}_{F-1}$ is the propellant flow rate of one F-1 engine, and t_i is the burn time for the i^{th} phase.

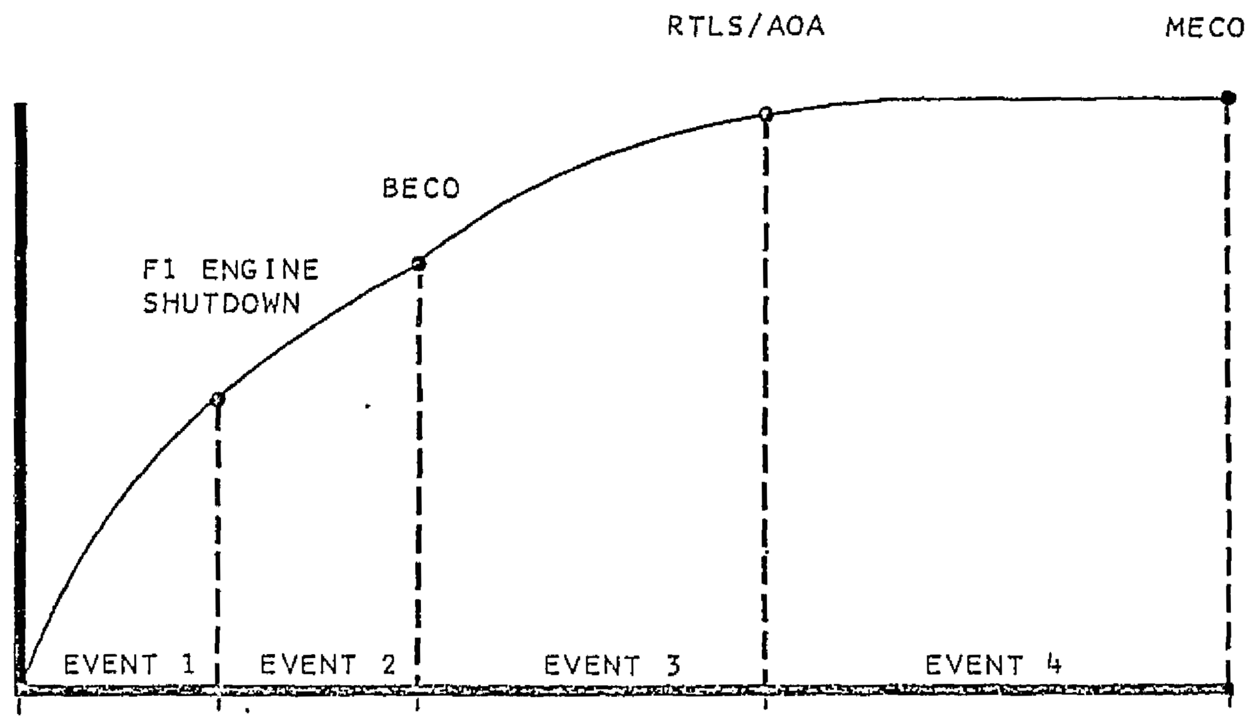
To determine the burn times t_1 and t_2 an effective propellant flow rate $\dot{W}_{eff}$ was used. The effective propellant flow rate for a given phase is defined as the total propellant burned during the phase divided by the phase burn time. The total propellant burned during the first phase is equivalent to the difference between GLOW and the vehicle weight at the point of F-1 shutdown. The burn time t_1 is then the weight difference, divided by the first-phase effective propellant flow rate. The remainder of the total first stage propellant, which was determined by SIZER, is divided by the second-phase effective propellant flow rate to yield the burn time t_2. These burn times are then used to calculate the LRB propellant. The ET propellant is then the difference between the total vehicle propellant and the amount of propellant allocated to the LRB.

WTORB, ETWT and LRBWT. - The programs WTORB, ETWT and LRBWT calculate component weights for the Orbiter, the ET and the LRB, respectively. The Orbiter component weights correspond to those of the February 1975 Orbiter, with the exception that a weight penalty is added to account for the additional structural weight necessary to accommodate the increased up payload. The ET is sized according to the ET propellant weight determined by PROP and a fixed mass fraction of .949 and includes 0.75% flight performance reserves. The LRB is sized according to the LRB propellant weight determined by PROP and weight estimating relationships (WER's) based on Saturn technology. A detailed discussion of the LRB WER's is presented in Appendix D of this report.

SEMF. - SEMF determines mass fractions for each stage from the LRB and ET inert weights determined by LRBWT and ETWT, respectively.

ROBOT. - ROBOT is the trajectory optimization program. ROBOT requires that the trajectory be divided into several thrust events. For example, in EDIN0501 the trajectory consisted of

four thrust events: F-1 shutdown, BECO/Separation, RTLS/AOA, and MECO/Injection. These thrust events are illustrated in figure 7 below.



EVENT 1 - F1 ENGINE SHUTDOWN
EVENT 2 - BECO/SEPARATION
EVENT 3 - RTLS/AOA
EVENT 4 - MECO/INJECTION

FIGURE 7   REFERENCED MISSION EVENTS.

Given GLOW and the burn time for the first thrust event, ROBOT will optimize the initial tilt rate, the exo-atmospheric pitch profile, and the burn times for any of the subsequent thrust events so that the optimum payload is achieved.

CONVG. - CONVG calculates and prints information that indicates how near the simulation is to convergence. Important parameters in determining whether or not convergence has been achieved are actual payload, stage ideal velocities, LRB and ET propellant actually burned during the trajectory, first stage average specific impulse, and first-phase effective propellant flow rate.

In addition to the above mentioned programs, which constitute the main loop of the simulation process, several other peripheral programs must be accessed in order to perform the simulation. A brief description of these programs and an explanation of how they are used in the simulation procedure are included later in this report.

Data Base Management

Communication among the various independent programs in the simulation process is accomplished through a common data base and DLG. The data base can be thought of as a collection of information which is stored on a temporary file during execution of the simulation. DLG is a program which, in conjunction with the subprogram ADDREL, transmits information from programs to the data base and from the data base to other programs. ADDREL causes data to be written in NAMELIST format on a temporary file. DLG then has the capability to incorporate this data into the data base. The sequence can be initiated in any program by the statement:

```
CALL ADDREL (fn,xHdbvn,n,pvn)
```

where fn is the number of the temporary file on which the data is to be written in NAMELIST format; dbvn is the name of a variable in the data base; x is the number of letters in the data base variable name; n is the number of elements to which the variable dbvn has been dimensioned; and pvn is the name of a variable in the program. The execution of this statement causes the variable dbvn to be set equal to the value assigned to the variable pvn in the calling program and this expression to be written in NAMELIST format on the temporary file fn.

If the command @USE NMLIST,fn has been previously included, the following sequence of commands will cause the value assigned

to the variable dbvn in NAMELIST format on the temporary file fn to be incorporated into the data base as the value corresponding to the data base variable dbvn:

```
@T.DLG,I DUM
'UPDATE DBASE'
'PROCESS NMLIST'
```

DLG recognizes certain commands within delimiters. The most important of these are:

'CREATE	-	Causes DLG to create a data base.
'DEFINE	-	Allows the parameter mentioned to be assigned a value in the data base and dimensions the parameter to its maximum number of values.
'ADD	-	Causes DLG to assign a new value to a variable in the data base.
'UPDATE	-	Causes DLG to prepare the data base to be interrogated and/or to receive new information through subsequent PROCESS and/or ADD commands.
'PROCESS	-	Causes DLG to incorporate the information contained on NMLIST (the temporary file on which ADDREL has been written) into the data base.
'PRINT	-	Causes the data base to be printed as a series of expressions of the form: variable name = value.

The data base can be interrogated to ascertain the current value of a data base variable by the following commands:

```
@T.DLG,IDUM
'UPDATE DBASE
 'name    '
```

where name is the data base variable name and the first column is left blank. The value of the variable will be printed out in as many spaces as there are between the delimiters (inclusive) in the interrogation command.

An alternate command to @T.DLG,I DUM is @T.DLG,IE DUM. The addition of the E causes the statement, ENTER A DIRECTIVE, to be written each time DLG is ready to receive a new instruction.

An element can be written in "skeleton" format by including DLG commands within delimiters among normal Fortran statements. The input elements to the main programs of the simulation, such as SIZERINPT, PROPINPT, ROBOTINPT, are written in skeleton format. If en1 is an element of file fn1 and is written in skeleton format, then the command:

```
@T.DLG fn1.en1,fn2.en2
```

will cause DLG to "fill out" the skeleton element en1 and place the filled out version in element en2 of file fn2. DLG fills out a skeleton element by executing the DLG commands within the delimiters in the skeleton and transferring all other statements intact from the input element to the output element. For example, SIZERINPT contains the following statements:

```
'UPDATE DBASE'
'PROCESS NMLIST'
@XQT SIM2.OSIZER
$IN
PAYLD='WTORB(28)-PLBIAS'
NSTAGE='NSTAGE',
VIDEAL='VIDEAL',
XLAMDP='XLAMDP',
XISP(1)='ISAVG',455.2,
WPEST='WP',
$END
@EOF
```

The command

```
@T.DLG SIM2.SIZERINPT,SIZERINPT
```

will first process whatever information exists on NMLIST and then construct an element SIZERINPT in TPF$ which consists of the following statements:

```
@XQT SIM2.OSIZER
$IN
PAYLD=100000.00000000000,
NSTAGE=2.000000,
VIDEAL=9144.5000000,21048.500000,
XLAMDP=.92138301501,.92652210593,
XISP=298.980,455.2,
WPEST=2977009.1250,1236229.2344.
$END
@EOF
```

In this manner, data base information can be transmitted from the data base to any program. Each of the input elements to the main programs begins with an UPDATE and PROCESS so that the latest information calculated in the most recently executed program will be available for input into the next program to be executed.

Procedure

Each of the EDIN05 simulations required a slightly modified procedure. The EDIN0501 study will be used to illustrate the EDIN05 design simulation procedure. The basic EDIN0501 design simulation procedure is illustrated in figure 8. Data flow among the various major programs is illustrated in figure 9.

The simulation is initiated by the command

```
@ADD SIM2.START
```

START is a partial run stream which performs the following functions:

1. Assigns files to which subsequent output can be breakpointed.
2. Assigns temporary files 25 and 14, on which data base information will reside during execution of the simulation.
3. Creates the data base by the following commands:

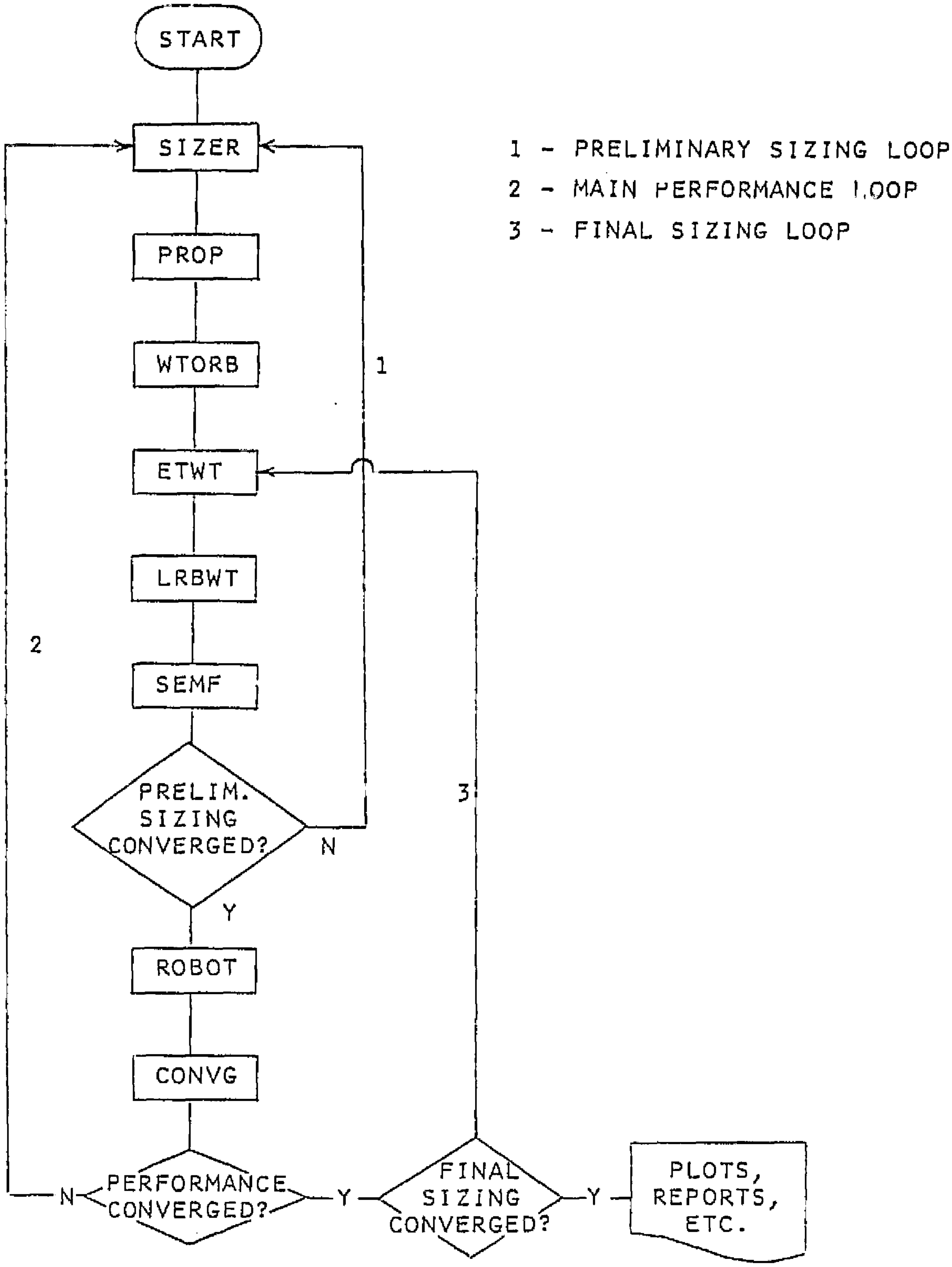


FIGURE 8 EDIN0501 PRIMARY CONVERGENCE LOOPS.

INPUT			OUTPUT	
ISAVG	(FROM ROBOT)	SIZER	WGLOW	(→ PROP)
VIDEAL	(FROM ROBOT)		WP	(→ PROP)
XLAMDP	(FROM SEMF)			
WDEFF	(FROM ROBOT)	PROP	TAUT	(→ ROBOT)
WGLOW	(FROM SIZER		WPROP	(→ LRBWT)
WP	(FROM SIZER		WPROP2	(→ ETWT)
VIDEAL	(FROM ROBOT)	ETWT	WET	(→ SEMF)
WP	(FROM SIZER,ROBOT)			
WPROP	(FROM PROP,ROBOT)			
WPROP2	(FROM PROP,ROBOT)			
WPROP	(FROM ROBOT)	LRBWT	XLAM	(→ ROBOT)
WBLOW	(FROM LRBWT)	SEMF	WGLOW	(→ ROBOT)
WET	(FROM ETWT)		XLAMDP	(→ SIZER)
WP	(FROM SIZER,ROBOT)			
WTORB	(FROM WTORB)			
TAUT	(FROM PROP)	ROBOT	TAUT	(→ CONVG)
WGLOW	(FROM SEMF)		VIDEAL	(→ SIZER)
XLAM	(FROM LRBWT)			
TAUT	(FROM ROBOT)	CONVG	ISAVG	(→ SIZER)
			PAY	
			WDEFF	(→ PROP)
			WP	
			WPROP	
			WPROP2	

EDIN0501 PARAMETERS	
ISAVG	STAGE AVERAGE SPECIFIC IMPULSE ARRAY.
PAY	ACTUAL PAYLOAD.
TAUT	PHASE BURN TIME ARRAY.
VIDEAL	STAGE IDEAL VELOCITY ARRAY.
WBLOW	BOOSTER LIFT-OFF WEIGHT.
WDEFF	FIRST STAGE EFFECTIVE PROPELLANT FLOW RATE ARRAY.
WET	ET LIFT-OFF WEIGHT.
WGLOW	GROSS LIFT-OFF WEIGHT.
WP	STAGE PROPELLANT WEIGHT ARRAY.
WPROP	LRB PROPELLANT WEIGHT.
WPROP2	ET PROPELLANT WEIGHT.
WTORB	ORBITER LIFT-OFF WEIGHT.
XLAM	LRB MASS FRACTION.
XLAMDP	STAGE MASS FRACTION ARRAY.

FIGURE 9 EDIN0501 DATA FLOW.

```
(1)  @T.DLG,I DUM
(2)  ADD SIM2.DEFINE/DBASE
(3)  @ADD SIM2.ADD/DBASE
(4)  @T.DLG,I DUM
(5)  @ADD SIM2.DEFINE/WBBASE
(6)  @ADD SIM2.ADD/WBBASE
```

Commands (1) through (3) create a data base named DBASE. DEFINE/DBASE contains the DEFINE statements which specify the names of the parameters that may be contained in the data base DBASE and dimensions those of the parameters which are arrays. ADD/DBASE contains the ADD statements which assign values to the parameters in the data base DBASE. Likewise, commands (4) through (6) create a data base named WBBASE. DBASE contains those parameters which are important in the sizing and performance aspects of the simulation. WBBASE contains parameters which pertain to the weight and balance and center of gravity aspects of the simulation.

Now that the data base has been created, the first objective is to obtain a preliminary vehicle sizing. This can be effected by the following commands:

```
@T.DLG S.SIZERINPT,SIZERINPT
@ADD SIZERINPT
```

The next step is to distribute the propellant between the LRB and the ET. The following commands accomplish this:

```
@T.DLG S.PROPINPT,PROPINPT
@ADD PROPINPT
```

When the propellant has been distributed, the major subsystems can be sized and component weight statements obtained by the commands:

```
@T.DLG S.WTORBINPT,WTORBINPT
@ADD WTORBINPT
@T.DLG S.ETWTINPT,ETWTINPT
@ADD WTWTINPT
@T.DLG S.LRBWTINPT,LRBWTINPT
@ADD LRBWTINPT
```

Now that the component weights of the vehicle have been determined, the actual mass fractions of this vehicle can be determined by the commands:

```
@T.DLG S.SEMFINPT,SEMFINPT
@ADD SEMFINPT
```

Generally the mass fractions calculated in SEMF will not be equivalent to those which were used in the initial sizing of the vehicle. This disparity indicates that the target payload will not be achieved exactly by this vehicle. As mentioned previously, SIZER used the ideal rocket equation to determine stage propellant weights. Assuming that the values used in SIZER for the stage ideal velocities and average specific impulses are accurate (i.e. the values used in SIZER exactly coincide with those which actually occur in ROBOT's simulated trajectory of the vehicle), SIZER will allocate exactly the amount of propellant that will enable the vehicle to achieve the target payload, but only if the mass fractions of the actual actual vehicle (determined in SEMF from the actual ET and LRB inert weights) match those used in SIZER exactly. If these mass fractions do not match exactly, then the inert weight (and thus the GLOW) of the actual vehicle will differ from that of the preliminary sizing, and this difference will result in the target payload not being achieved exactly. Therefore, the sizing loop, loop 1 in figure 8, must be iterated until the mass fractions input into SIZER and those subsequently output by SEMF converge. The mass fractions can be considered converged if they are within .00002 for each stage. This difference will usually be accompanied by a difference in GLOW between the preliminary and actual vehicles of less than 500 lbs. For a reasonably close initial estimate for the mass fractions, convergence of the sizing loop can usually be achieved in three iterations, if the values output from SEMF at the end of one iteration are input into SIZER at the beginning of the next.

When the sizing has been converged, the next step is to use ROBOT to optimize the trajectory. In order to ensure that ROBOT converges on the optimum trajectory, the input stream ROBOTINPT contains two (2) consecutive cases. In the first case, the vehicle is flown only to the RTLS point. This allows the initial portion of the trajectory to become optimized so that, when the program is restarted in the second case, ROBOT begins with an initial tilt rate and exo-atmospheric pitch profile that is usually much more accurate than that initially

input. In the second case, the trajectory is completed by the addition of the MECO point. This input setup for the ROBOT program usually produces a trajectory that is solidly converged. ROBOT has the capability to vary the time at which staging occurs in such a way that the propellant, and thus the ideal velocity, distribution between the stages is the one which will permit the maximum payload. ROBOT is executed by the following commands:

```
@T.DLG S.ROBOTINPT,ROBOTINPT
@ADD ROBOTINPT
```

The next step in the simulation procedure is to execute CONVG to ascertain whether or not the design has converged. CONVG can be executed by the commands:

```
@T.DLG S.CONVGINPT,CONVGINPT
@ADD CONVGINPT
```

Generally, the stage ideal velocities and first stage average specific impulse calculated by CONVG from ROBOT output will not match exactly those that were used in the preliminary sizing of the vehicle in SIZER. Therefore, the amount of propellant which SIZER allocated is inaccurate and the target payload consequently has not been achieved. Furthermore, if the effective propellant flow rate for the first thrust event is not equivalent to that used to determine the first phase burn time in PROP, then this burn time is also inaccurate and is another cause of the discrepancy between the target payload and the actual payload. For these reasons, the main performance loop, loop 2 in figure 8, must be iterated until the stage ideal velocities and first stage average specific impulse input into SIZER and the first-phase effective propellant flow rate input into PROP all coincide with the values subsequently calculated by CONVG. At this time, the actual payload will very closely match the target payload and the simulation can be considered converged. The ideal velocities can be considered converged if they are within about 10 feet/second for each stage, the first stage average specific impulse if it is within 0.1 second, the first-phase effective propellant flow rate if it is within 1.0 pound/second, and the payload if it is within 50 pounds. For reasonably close initial estimates of these parameters, convergence of the main performance loop can usually be achieved in about six iterations, if the values output from CONVG at the end of one iteration are used as the input values at the beginning of the next.

When the main performance loop is judged to have converged, there will usually be a discrepancy between the amount of propellant allocated to the LRB by PROP and that actually consumed during the trajectory, and between the amount allocated to the ET and that actually consumed. This discrepancy (up to $\pm$ 3000 to 4000 pounds in each component) is due to the cumulative effects of small differences in mass fractions, stage ideal velocities, first stage average specific impulse, and first-phase effective propellant flow rate between input and output. However, the total propellant actually consumed is usually very close to the amount allocated (usually less than 500 pounds difference). The discrepancy can thus be considered small, since it indicates an error in burn time of less than 0.2 seconds, but it cannot be considered negligible. Therefore, it is necessary to perform the final sizing loop, loop 3 in figure 8, once to slightly modify the sizing of the ET and the LRB to accommodate the small change in propellant capacity. The ET and LRB propellant actually consumed are input into ETWT and LRBWT so that the ET and LRB are resized. This will result in a slightly modified GLOW and the sequence of equations from PROP which determines the first and second phase burn times must be inserted after the calculations of GLOW in SEMF so that these burn times can be recalculated and supplied to ROBOT as accurately as possible.

A slightly modified input must be provided to ROBOT for its final execution. The element S.ROBOTINPT2A must therefore be edited into S.ROBOTINPT before ROBOT is executed for the final time. For all previous executions of ROBOT, however, S.ROBOTINPT has been identical to S.ROBOTINPT2. The only difference between the elements ROBOTINPT2 and ROBOTINPT2A is that the former causes ROBOT to optimize the second burn time, while the latter does not (so that the allocated amount of LRB and ET propellant will be burned as closely as possible). Naturally, since time to BECO is fixed in the final execution of ROBOT, there will be a small decrease in performance. Therefore, the target payload according to which the sizing has been converged should be slightly higher than that actually desired. In this way, the decrease in performance due to not optimizing the second burn time in the final execution of ROBOT can be anticipated, so that the final payload will be that which is desired. The payload penalty for holding the second burn time constant in the final ROBOT execution is approximately 200 pounds.

Since many of the main programs must be executed over and over again in the same order during the simulation process, partial run streams were created to lessen the typographical demands upon the user. The command @ADD S.TEST1 executes SIZER, PROP and WTORB. The command @ADD S.TEST2 executes ETWT, LRBWT and

SEMF. The command @ADD S.TEST3 breakpoints the print, executes ROBOT, breakpoints back to the user, and then searches the breakpoint file for lines which indicate how the convergence of the trajectory is progressing and prints the trajectory convergence history at the user's terminal. In practice, it is most efficient to breakpoint all print and then search the breakpoint file for the most pertinent information. For example, one iteration of the preliminary sizing loop can be performed by using the commands:

```
@ADD S.TEST1
@@CQUE
@ADD S.TEST2
@@END
```

However, the entire preliminary sizing loop can be most efficiently performed by using the following commands:

```
@BRKPT PRINT$/BK1
@@CQUE
@ADD S.TEST1
@ADD S.TEST2
@ADD S.TEST1
@ADD S.TEST2
@ADD S.TEST1
@ADD S.TEST2
@BRKPT PRINT$
@ED,R BK1.
LC LAM
LC GROSS STAGE
LC GLOW
LC MAIN PROP
@@END
```

This particular sequence will cause the sizing effective mass fractions, the GLOW calculated by SIZER, the GLOW calculated by SEMF, and the propellant weights of both the ET and the LRB to be printed at the user's terminal for each of the three iterations. One iteration of the main performance loop comprises the above commands and the following:

```
@ADD S.TEST3
@T.DLG S.CONVGINPT,CONVGINPT
@@CQUE
@BRKPT PRINT$/BK3
@ADD CONVGINPT
@BRKPT PRINT$
@ED,R BK3.
P!
@@END
```

This particular sequence will cause the trajectory convergence history and the simulation convergence data to be printed at the user's terminal.

The final sizing loop can be executed by preceding the command @ADD S.TEST3 with the command @ADD S.TEST2 in the sequence immediately above.

If the user desires a complete printing of a breakpoint file, he should assign a catalogued public file, copy the breakpoint file to the fresh file, and execute the print from the fresh file, so that the same breakpoint files will always be available for use.

When the design has converged and the final sizing loop has been executed, the next task is the saving of the data base and plot information. During execution of a simulation, the data base is temporarily stored on file 25 and temporary file 14 is used as the file on which ADDREL writes data for updating the data base. Furthermore, each execution of ROBOT produces a collection of information, which is stored temporarily on file 11 for future use in constructing plots of the trajectory. When the simulation has converged, file 11 should be copied to a permanent data file, such as BDATA2. Then, the following command will save the plot data as an element of the file SIM2:

```
@ADD S.SAVPLT
```

SAVPLT is a partial run stream that executes the program XLT, which translates binary data into other formats. In this case, XLT writes the binary data from BDATA2 in decimal notation as an element of SIM2. The translating program is actually executed twice, once to create an element of plot data for the ascent trajectory and once to create an element of plot data for the reentry trajectory of the LRB, which ROBOT also calculates.

The data base can be saved by the following sequence of commands:

```
@ASG,T TEMP1.
@T.DLG,I DUM
@@BRKPT PRINT$/TEMP1
 'PRINT DBASE'
@@BRKPT PRINT$
@ADD S.SAVEDB
```

This procedure must be carried out twice, once to save the data base DBASE as an element of SIM2, and once to save the data base WBBASE as an element of SIM2. In the latter case, the command 'PRINT DBASE' in the above sequence should be replaced by 'PRINT WBBASE'.

The user should periodically store the data base and plot information on permanent data files in order to protect himself in case the system goes down during execution of a simulation. This can be accomplished by the following commands:

```
@ERS BDATA1.
@ERS BDATA2.
@COPY 25,BDATA1
@COPY 11, BDATA2
```

If the system does go down or execution of the simulation is otherwise terminated, the user can resume the simulation from the point at which he last saved the data base by the following command

```
@ADD SIM2.TRANS
```

TRANS performs the same functions as START, with the exception that instead of creating the data base from elements previously stored on SIM2 by using SAVEDB, it creates the data base by the following commands:

```
@COPY BDATA1,25
@COPY BDATA2,11
```

When the final sizing loop has been completed and the data bases and plot information stored, the next step is to obtain plots of the trajectory. The PLOTTR program, which produces these plots, is executed by using the ROPLOT elements of SIM2.

The seven ROPLOT elements, one for each plot, are input streams which provide PLOTTR with such information as the scale and headings to be used on the plots and the name of the element which contains the data. The ROPLOT elements must be "filled out" by DLG in the same manner as the input elements to the programs in the main loops of the simulation sequence. This process can be easily carried out by the command:

```
@ADD S.TEST5
```

TEST5 fills out each of the ROPLOT elements and creates for each an element in TPF$ which has the same name as the version name of the ROPLOT element from which it was constructed. For example, the first line of TEST5:

```
@T.DLG S.ROPLOT/STATE,STATE
```

creates a filled-out element named STATE in TPF$. The plots can now be obtained by adding these elements in TPF$. STATE must be added initially, because it contains information necessary in all of the other plots. Likewise, HV must be added before RSTATE and HEAT.

CALCOMP copies of the plots can be obtained through the use of the program CALCOPY. However, it is not necessary that the user ever directly access CALCOPY, since all the necessary instructions to CALCOPY are included in the ROPLOT elements. STATE is currently set up so that the plots are written on temporary file 18. Therefore, the statement @ASG,T 18. must be included before any of the plots are constructed. Then, the filled out elements in TPF$ may be added sequentially. To ensure that the plot data written on the data file does not exceed the file's maximum capacity of 128 blocks, it is usually a good idea to use the following commands to construct and store the plots:

```
@ASG,T 18.
@ADD STATE
@ADD LOADS
@ADD PROP
@ADD ATCON
 $IN STOP=T $
@ERS dfl.
@COPY 18.,dfl.
@FREE 18.
```

```
@ASG,T 18.
@ADD STATE
@ADD HV
@ADD RSTATE
@ADD HEAT
 $IN STOP=T $
@ERS df2.
@COPY 18.,df2
```

Thus, the plots are saved on two permanent data files: STATE, LOADS, PROP and ATCON on df1, and STATE,HV,RSTATE and HEAT on df2. Note that STATE must be the first element added whenever the plots are reinitiated on a new file. The statement:

```
$IN STOP=T $
```

is necessary in order to tell CALCOPY when to stop reading data from the input file. CALCOMP plots can then be obtained by submitting two batch jobs, each consisting of the following cards:

```
@RUN...
@ASG,T 19.,8C,CALP1
@ASG,T 18.
@COPY df.,18.
@XQT CALCOMP.OCALCOPY
 $IN LUPVEC=18,STOP=F,$
@FIN
```

where df is the appropriate data file name.

Several engineering-type reports can be obtained once the design has been optimized. The skeleton elements S.CONPTREP,.SUMREP, and .TRAJREP can be filled out and printed to provide a basic concept report, weight summary, and trajectory summary, respectively, by the following commands:

```
@T.DLG,IO DUM
@ADD S.CONPTREP
@ADD S.SUMREP
@ADD S.TRAJREP
```

The final report which can be obtained is the detailed mass properties report. The element TEST6 calculates weight-and-balance and center-of-gravity information for the ET and the LRB, using the elements WABINPT/ET, WABINPT/LRB, LRBCGINPT, LRBARYINPT, and WABB/05, and produces a summary mass properties report from MASSPROP/RPT. Thus, all mass properties information can be obtained by the command @ADD S.TEST6.

Finally, a print of the current data base and a listing of the SIM2 file can be obtained by the command @ADD SIM2.FLIST.

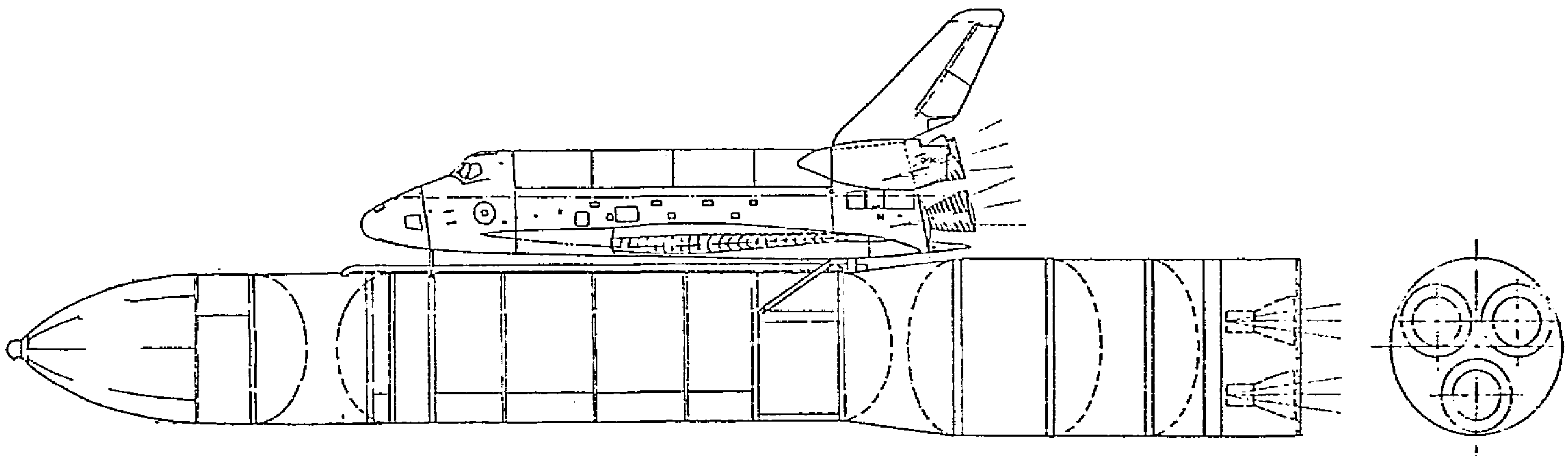


FIGURE 11 EDIN0501 CONFIGURATION

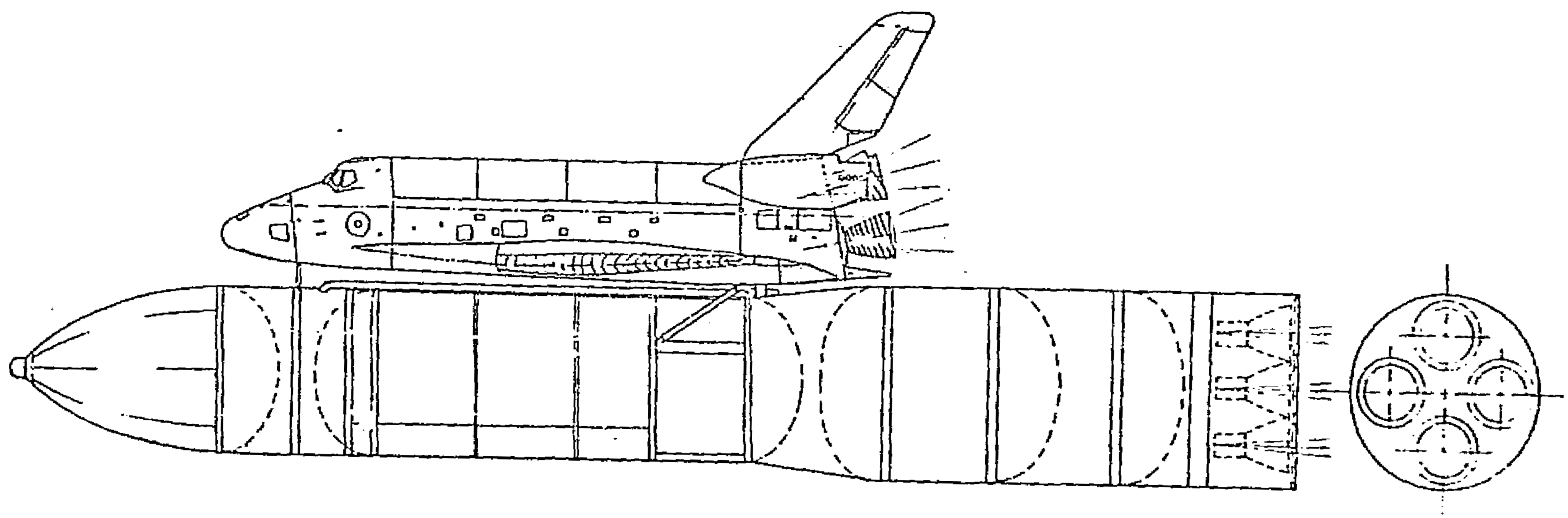


FIGURE 12   EDIN0505 CONFIGURATION

DISCUSSION OF RESULTS

Configuration Descriptions

Four basic configurations were investigated in the EDIN05 design series:

1. A parallel burn vehicle with an F-1 engine-powered LRB.
2. A parallel burn vehicle with a high-pressure engine powered LRB.
3. A series burn vehicle with an F-1 engine-powered LRB.
4. A series burn vehicle with a high-pressure engine-powered LRB.

The EDIN05 study series comprised ten individual design simulations, which are briefly described below.

STUDY NO.	
EDIN0501	LRB sized for three F-1, ET resized to minimize GLOW for 100K up-payload; parallel burn.
EDIN0502A	EDIN0501 LRB modified for seven 680K sea-level thrust high - Pc engine propulsion system, EDIN0501 ET, maximum payload determined, parallel burn.
EDIN0502B	EDIN0502A LRB, ET resized to maximize payload, parallel burn.
EDIN0503	EDIN0501 LRB modified for six 800K sea-level thrust high-Pc engine propulsion system, EDIN0501 ET maximum payload determined; parallel burn.
EDIN0504	LRB sized for optimum T/W using rubber high-Pc engines based on 800K Beichel, ET resized to minimize GLOW for 140K up-payload; parallel burn.
EDIN0504A	LRB sized for optimum T/W using rubber high-Pc engines based on 800K Beichel, ET resized to minimize GLOW for 150K up-payload; parallel burn.
EDIN0504B	EDIN0504A LRB modified for three F-1, EDIN0504A ET, maximum payload determined; parallel burn.
EDIN0504C	LRB sized for optimum T/W using rubber high-Pc engines based on 800K Beichel, ET resized to minimize GLOW for 150K up-payload; series burn.
EDIN0504D	EDIN0504C LRB modified for four F-1, EDIN0504C ET, maximum payload determined; parallel burn.
EDIN0505	LRB sized for four F-1, ET resized to minimize GLOW for 100K up-payload; series burn.

EDIN05 RESULTS SUMMARY

	SHUTTLE	501	502A	502B	503	504	504A	504B	504C	504D	505
LRB	SRB	Sized for 3 F-1	501 w/ (7) 680K Hi-Pc	501 w/ (6) 800K Hi-Pc	501 w/ (6) 800K Hi-Pc	Sized for opt. T/W Hi-Pc	Sized for opt. T/W Hi-Pc	504A w/ 3 F-1	Sized for opt. T/W Hi-Pc	504C w/ 4 F-1	Sized for 4 F-1
ET	–	R	501	R	501	R	R	504A	R	504C	R
PL	65K	100K	D	M	D	140K	150K	D	150K	D	100K
TYPE	P	P	P	P	P	P	P	P	S	S	S
GLOW	4.203M	4.835M	4.817M	4.928M	4.698M	4.261M	4.804M	4.598M	4.587M	4.344M	4.795M
T/W	1.491	1.240	1.236	1.209	1.283	1.236	1.350	1.308	1.345	1.479	1.340
LRB LIFT-OFF	2.327M	2.760M	2.693M	2.693M	2.569M	2.055M	2.562M	2.428M	2.898M	2.760M	3.186M
LRB PROPELLANT	2.019M	2.506M	2.459M	2.459M	2.335M	1.855M	2.333M	2.180M	2.642M	2.468M	2.919M
LRB INERT	309K	254K	234K	234K	234K	200K	228K	248K	256K	292K	265K
ET LIFT-OFF	1.626M	1.805M	1.805M	1.911M	1.805M	1.879M	1.905M	1.905M	1.351M	1.324M	1.322M
ET PROPELLANT	1.540M	1.707M	1.707M	1.807M	1.707M	1.777M	1.801M	1.801M	1.276M	1.248M	1.251M
ET INERT	86.3K	98.0K	98.0K	104.1K	98.0K	102.5K	103.9K	103.9K	75.2K	75.2K	73.0K
PAYLOAD	65K	100K	132K	137K	136K	140K	150K	78.5K	150K	73.3K	100K

D - Determined
M - Maximized
P - Parallel Burn
R - Resized
S - Series Burn

EDIN0501

The EDIN0501 configuration consists of an LRB powered by three F-1 engines, a resized ET and an Orbiter. It is a parallel-burn vehicle, designed to achieve an 100K up-payload under Space Shuttle Reference Mission 1 groundrules. GLOW for this vehicle is 4.835 X 10^6 lbs., with LRB and ET lift-off weight of 2.76 X 10^6 lbs. and 1.805 X 10^6 lbs., respectively. Thus, the EDIN0501 configuration requires an ET approximately 13.6% larger than the baseline Shuttle ET.

				F-1 SHUTDOWN		BECO		RTLS		MECO	
PARAMETER	LIFT-OFF	MAX Q	MAX ACCEL	PRIOR	POST	PRIOR	POST	PRIOR	POST	PRIOR	POST
TIME (SEC)	0.0	81.6	125.4	132.8	132.8	141.0	141.0	262.4	262.4	532.0	532.0
WEIGHT (LBS.)	4852515	309885	2156372	2002415	2002415	1875506	1621493	1211818	1211818	385264	287224
REL V (FPS)	0	1452	3933	4528	4528	5137	5137	8140	8140	24300	24300
ALT (FT.)	0	42288	113204	128769	128769	146942	146942	348564	348564	348564	394478
REL FPA (DEG)	0.00	55.30	31.27	28.64	28.64	26.05	26.05	8.27	8.27	0.53	0.53
Q (PSF)	0	607	138	91	91	55	55	0	0	0	0
ACCEL (G)	1.24	1.92	3.00	3.00	2.66	2.85	0.93	1.27	1.16	3.00	0.00

EDIN0502A

The major design requirement for the EDIN0502A study was to replace the three F-1 engines in the EDIN0501 LRB with seven of the 680,000 lb. sea-level thrust high-pressure engines proposed by Beichel, while maintaining the identical EDIN0501 booster airframe and ET. Since the two engines operate at different mixture ratios, the EDIN0502A fuel tank could not be completely filled. GLOW for this vehicle was 4.817×10^6 lbs. and an up-payload capability of 132K was obtained.

				BECO		RTLS		MECO	
PARAMETER	LIFT-OFF	MAX Q	MAX ACCEL	PRIOR	POST	PRIOR	POST	PRIOR	POST
TIME (SEC)	0.0	81.9	146.2	167.3	167.3	236.5	236.5	531.0	531.0
WEIGHT (LB)	4817349	3320530	2146228	1793885	1559874	1326392	1326392	417338	319299
REL V (FPS)	0	1319	4685	6414	6414	8140	8140	24299	24299
ALT (FT)	0	40700	153636	207760	207760	348579	348579	394436	394436
REL FPA (DEG)	0.00	61.73	30.68	24.97	24.97	8.27	8.27	0.53	0.53
Q(PSF)	0	534	35	9	9	0	0	0	0
ACCEL (G)	1.24	1.82	3.00	3.00	0.98	1.16	1.06	3.00	0.00

EDIN0502B

The EDIN0502B configuration was identical to that of EDIN0502A, with the exception that the ET was resized. This provided a GLOW of 4.928 X 10^6 lbs., an ET lift-off weight of 1.911 X 10^6 lbs., and a payload potential of 136.9K. Thus, an increase of 100,000 lbs. of ET propellant yields a payload increase of 4,900 lbs. over the EDIN0502A configuration.

				BECO		RTLS		MECO	
PARAMETERS	LIFT-OFF	MAX Q	MAX ACCEL	PRIOR	POST	PRIOR	POST	PRIOR	POST
TIME (SEC)	0.0	85.6	152.3	166.1	166.1	257.2	257.2	560.9	560.9
WEIGHT (LB)	4928000	3364347	2145955	1908722	1674712	1366950	1366950	428280	324135
REL V (FPS)	0	1312	4846	5990	5990	8140	8140	24300	24300
ALT (FT)	0	41312	153714	185547	185547	348565	348565	394340	394340
REL FPA (DEG)	0.00	60.62	27.33	23.43	23.43	8.27	8.27	0.53	0.53
Q (PSF)	0	515	37	18	18	0	0	0	0
ACCEL (G)	1.21	1.80	3.00	3.00	0.91	1.12	1.03	3.00	0.00

EDIN0503

The objective of the EDIN0503 study was to replace the three F-1 engines in the EDIN0501 LRB with six of the 800,000 lbs. sea-level thrust high-pressure engines proposed by Beichel, while maintaining the identical EDIN0501 booster airframe and ET. Since the high-Pc engines were operated at a mixture ratio of 2.9, as opposed to 2.27 for the F-1's, a large portion of the fuel tank was left unfilled. GLOW was 4.698 X 10^6 lb. and a payload of 136.1 K was obtained.

				BECO		RTLS		MECO	
PARAMETER	LIFT-OFF	MAX Q	MAX ACCEL	PRIOR	POST	PRIOR	POST	PRIOR	POST
TIME (SEC)	0.0	77.9	140.8	161.4	161.4	233.3	233.3	531.2	531.2
WEIGHT (LBS)	4697615	3292842	2159332	1818218	1584205	1341576	1341576	421451	323412
REL V (FPS)	0	1342	4677	6367	6367	8141	8141	24300	24300
REL FPA (DEG)	0.00	61.52	30.58	24.96	24.96	8.27	8.27	0.53	0.53
ALT (FT)	0	40242	150895	203447	203447	348538	348538	394260	394260
Q (PSF)	0	562	39	10	10	0	0	0	0
ACCEL (G)	1.28	1.84	3.00	3.00	0.97	1.15	1.05	3.00	0.00

EDIN0504

The EDIN0504 study was conducted to size a parallel-burn vehicle using rubber high-pressure engines based on the 800,000 lbs. sea-level thrust Beichel engine operating at a mixture ratio of 2.9, a resized ET, and an Orbiter to achieve an 140K up-payload under Shuttle Reference Mission 1 groundrules. The lift-off T/W chosen was the highest for which engine throttling was not required to limit dynamic pressure. This T/W was 1.236 and provided a GLOW of 4.261 X 10^6 lbs., an LRB lift-off weight of 2.055 X 10^6 lbs., and an ET lift-off weight of 1.879 X 10^6 lbs. The reasons why this vehicle is so much smaller than the EDIN0502 and EDIN0503 configuration, yet achieved a greater payload, are that its propellant tanks were completely filled and that the relative sizes of the LRB and ET were optimized to achieve the 140K payload with minimum GLOW.

				BECO		RTLS		MECO	
PARAMETER	LIFT-OFF	MAX Q	MAX ACCEL	PRIOR	POST	PRIOR	POST	PRIOR	POST
TIME (SEC)	0.0	80.0	133.7	150.7	150.7	246.9	246.9	551.9	551.9
WEIGHT (LB)	4261416	2997653	2149470	1898021	1697602	1373038	1373038	429912	327454
REL V (FPS)	0	1420	4520	5921	5921	8140	8140	24300	24300
REL FPA (DEG)	0.00	57.03	29.63	24.66	24.66	8.27	8.27	0.53	0.53
ALT (FT)	0	39422	132238	172525	172525	348580	348580	394232	394232
Q (PSF)	0	650	78	27	27	0	0	0	0
ACCEL (G)	1.24	1.93	3.00	3.00	0.90	1.12	1.03	3.00	0.00

EDIN0504A

The EDIN0504A study had the same objectives as those of EDIN0504, with the exception that the engines were operated at a mixture ratio of 2.5 and the vehicle was sized to obtain a payload of 150K. The lift-off T/W was 1.35 and GLOW was 4.804M, the half million pounds increase in GLOW over the EDIN0504 configuration going mainly to the LRB. The LRB lift-off weight is 2.562 X 10^6 lbs. and the ET lift-off weight is 1.905 X 10^6 lbs. Thus, the ET required by the EDIN0504A configuration is about 20% larger than the baseline Shuttle ET.

				BECO		RTLS		MECO	
PARAMETER	LIFT-OFF	MAX Q	MAX ACCEL	PRIOR	POST	PRIOR	POST	PRIOR	POST
TIME (SEC)	0.0	72.8	124.7	143.4	143.4	244.2	244.2	559.8	559.8
WEIGHT (LBS)	4804693	3359449	2329684	1987399	1758988	1418661	1418661	441969	338037
REL V (FPS)	0	1452	4405	5948	5948	8140	8140	24299	24299
REL FPA (DEG)	0.00	56.20	29.13	23.70	23.70	8.27	8.27	0.53	0.53
ALT (FT)	0	40580	128313	171032	171032	348577	348577	394276	394276
Q (PSF)	0	649	143	29	29	0	0	0	0
ACCEL (G)	1.35	1.90	3.00	3.00	0.87	1.08	0.99	3.00	0.00

EDIN0504B

The major design requirement of the EDIN0504A study was to replace the high-Pc engines in the EDIN0504A LRB with three F-1 engines, while maintaining the identical EDIN0504A ET and booster airframe (except for the propulsion system weight). The oxygen tank was left partially unfilled, due to the mixture ratio disparity. The vehicle GLOW was 4.598×10^6 lbs., the lift-off weight of the modified LRB was 2.428×10^6 lbs., and a payload of 78.5K was achieved.

			BECO		RTLS		MECO	
PARAMETER	LIFT-OFF	MAX Q	PRIOR	POST	PRIOR	POST	PRIOR	POST
TIME (SEC)	0	71.0	120.3	120.3	309.6	309.6	568.4	568.4
WEIGHT (LBS)	4598410	3084122	2045733	1797993	1158705	1158705	369715	265783
REL V (FPS)	0	1352	4251	4251	8145	8145	24310	24310
REL FPA (DEG)	0.00	56.03	28.15	28.15	8.29	8.29	0.55	0.55
ALT (FT)	0	36842	113461	113461	348946	348946	396395	396395
Q (PSF)	0	650	159	159	0	0	0	0
ACCEL (G)	1.31	1.69	3.00	0.81	1.33	1.22	3.00	0.00

EDIN0504C

The objective of the EDIN0504C study was to size a series-burn vehicle to meet the same mission requirements as the EDIN0504A configuration. The LRB was powered by high-pressure engines based on the 800,000 lb. sea-level thrust Beichel engine operating at a mixture ratio of 2.5. Again the lift-off T/W chosen was the highest for which engine throttling was not required to limit dynamic pressure. This T/W was 1.345 and provided a GLOW of 4.587×10^6 lbs., an LRB lift-off weight of 2.898×10^6 lbs., and an ET lift-off weight of 1.351×10^6 lbs. The GLOW of this series-burn configuration is over 200,000 lbs. lower than that of the parallel-burn configuration (EDIN0504A) designed to perform the same mission. Furthermore, the ET is 27.6% smaller than the parallel-burn ET.

				BECO		RTLS		MECO	
PARAMETER	LIFT-OFF	MAX Q	MAX ACCEL	PRIOR	POST	PRIOR	POST	PRIOR	POST
TIME (SEC)	0	73.3	123.3	138.4	138.4	250.2	250.2	541.6	541.6
WEIGHT (LBS)	4586903	3178728	2216445	1945392	1698608	1312103	1312103	413396	338235
REL V (FPS)	0	1459	4317	5556	5556	8140	8140	24300	24300
REL FPA (DEG)	0.00	55.68	29.34	24.66	24.66	8.28	8.28	0.53	0.53
ALT (FT)	0	40820	124473	158010	158010	348572	348572	394359	394357
Q (PSF)	0	650	100	41	41	0	0	0	0
ACCEL (G)	1.35	1.90	3.00	3.00	0.90	1.17	1.07	3.00	0.00

EDIN0504D

The EDIN0504D configuration was identical to that of EDIN0504C, with the exception that the high-Pc engines in the EDIN0504C LRB were replaced by four F-1 engines and the propulsion system weights were modified. Again, the oxygen tank was left partially unfilled, due to the mixture ratio disparity. The vehicle GLOW was 4.344×10^6 lbs., the lift-off weight of the modified LRB was 2.76×10^6 lbs., and a payload of 73.3K was achieved. Due to the high lift-off T/W of 1.479, an F-1 engine was shut down at 45.75 seconds to limit dynamic pressure to 650 psf.

		F-1 SHUTDOWN		BECO		RTLS		MECO	
PARAMETER	LIFT-OFF	PRIOR	POST	PRIOR	POST	PRIOR	POST	PRIOR	POST
TIME (SEC)	0	45.75	45.75	121.0	121.0	281.2	281.2	517.3	517.3
WEIGHT (LBS)	434460	3239083	3239083	1876204	1584193	1043308	1043308	335744	260582
REL V (FPS)	0	1026	1026	3957	3957	8140	8140	24299	24299
REL FPA (DEG)	0.00	73.80	73.80	34.44	34.44	8.27	8.27	0.53	0.53
ALT (FT)	0	20510	20510	137056	137056	348554	348554	394606	394606
Q (PSF)	0	646	646	49	49	0	0	0	0
ACCEL (G)	1.48	1.89	1.37	2.78	0.96	1.47	1.35	3.00	0.00

EDIN0505

The EDIN0505 study was conducted to size a series-burn vehicle, using four F-1 engines in the LRB, to achieve the same mission requirements as the EDIN0501 configuration. GLOW was 4.795×10^6 lbs., the LRB lift-off weight was 3.186×10^6 lbs., and the ET lift-off weight was 1.322×10^6 lbs. Comparison of this configuration with the parallel-burn vehicle designed to perform the same mission (EDIN0501) indicates that the GLOW savings of the series-burn vehicle is negligible, but that a 25.5% smaller ET is required by the series burn. An F-1 engine was shut down at 62.5 seconds to limit dynamic pressure to 650 psf.

		F-1 SHUTDOWN		BECO		RTLS		MECO	
PARAMETER	LIFT-OFF	PRIOR	POST	PRIOR	POST	PRIOR	POST	PRIOR	POST
TIME (SEC)	0	62.5	62.5	140.2	140.2	283.3	283.8	536.0	536.0
WEIGHT (LBS)	4795175	3285188	3285188	1876474	1611545	1126889	1126889	360690	287615
REL V (FPS)	0	1217	1217	4577	4577	8140	8140	24297	24297
REL FPA (DEG)	0.00	66.59	66.59	24.39	24.39	8.27	8.27	0.53	0.53
ALT (FT)	0	30750	30750	149411	149411	348554	348554	394512	394512
Q (PSF)	0	651	651	39	39	0	0	0	0
ACCEL (G)	1.34	1.87	1.35	2.78	0.94	1.36	1.25	3.00	0.00

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APPENDIX A - WEIGHT ESTIMATING RELATIONSHIPS

The weight estimating relationships (WER'S) developed for the EDIN05 study were patterned after the techniques utilized by the Space Shuttle Synthesis Program (reference 1). Because of the wide range of design parameters, and the many possible design solutions in any area of vehicle design, the algorithms used are in general terms. Although the equations are in general terms, the inputs are often the result of extensive study of a specific design solution.

The following sections describe the WER's used in this study.

Body Structure

The body structure is assumed to consist of support structures as well as all load carrying members. The component structures which comprise the body structure are:

1. Integral LOX Tank.
2. Integral RP-1 Tank.
3. Interstage structure between the booster and the ET.
4. The thrust structure.

The equation which sums these component structures is:

WSTRT=WSTR1+WSTR2+WSTR3+WSTR4+WSTR5

where:

WSTRT=Body structure weight, lbs.

WSTR1=Integral LOX tank weight, lbs.

WSTR2=Integral RP-1 tank weight, lbs.

WSTR3=Interstage weight, lbs.

WSTR4=Aft skirt weight.

WSTR5=Thrust structure weight, lbs.

Integral LOX Tank. - The integral LOX tank is sized as a function of total tank volume, including ullage, residuals and reserves. It is assumed to be a load carrying structure consisting of a frame, barrel, intertank frame, domes and baffles. The equation for the weight estimation was obtained from reference 1.

The equation for integral LOX tank weight is:

WSTR1=CSTR1 (VOXT)

where:

WSTR1=Integral LOX tank weight, lbs.

CSTR1=LOX tank weight coefficient, lbs/cu ft.

VOXT=Total volume of the oxidizer tank, cu ft.

The coefficient CSTR1 was obtained from figure and is representative of Saturn Technology which is illustrated by the broken line. The slope CSTR1 of the line is.810. A 3.0 percent ullage was assumed.

Integral RP-1 Tank. - The integral fuel is sized as a function of total tank volume including ullage, residuals and reserves. The tank is assumed to be a load carrying structure. The equation for weight estimation was obtained from reference 1.

The equation for integral fuel tank weight is:

WSTR1=CSTR2 (VFLT)

where:

WSTR1=Integral fuel tank weight, lbs.

CSTR1=fuel tank weight coefficient, lbs/cu ft.

VFLT =Total volume of fuel tank, cu. ft.

The coefficient CSTR1 was obtained from figure and is representative of Saturn Technology which is illustrated by the broken line. The slope CSTR1 of the line is.877. A3.0 percent ullage was assumed.

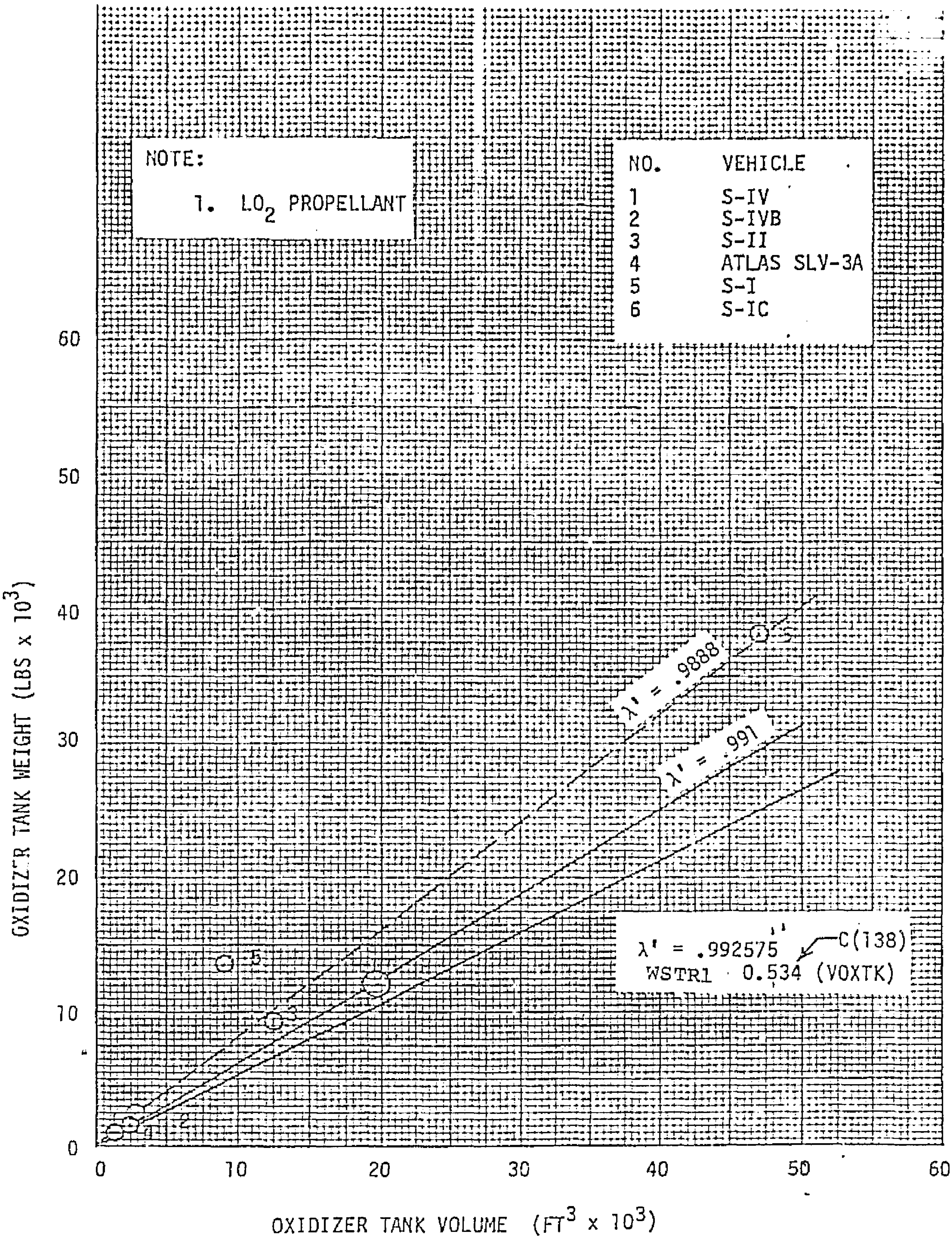


FIGURE VOLUME VERSUS LOX TANK WEIGHT.

Interstage Structure. - The interstage structure is assumed to consist of all fillings, supports and load carrying members between the booster stage and the ET. The equation which sizes the interstage was obtained from reference 1. The equation scales the weight as a function of wetted area.

The equation for the interstage structure is:

WSTR3=CSTR3((ADIA/2+EDIA/2) (PI) (ADIA/2+EDIA/2)^2 + (TINSTG)^2)

where:

Total weight of the interstage structure, lbs.

PI =Constant (3.1415)

ADIA =Diameter of stage, ft.

EDIA =Diameter of ET ft.

TINSTG=Length of the interstage, ft.

CSTR3 =Scaling coefficient

The value of 4.0 lbs/sq ft. is representative of Saturn IC Technology (reference 1) to which the interstage was scaled.

Aft Skirt. - The aft skirt structure is sized as a function of wetted area. The equation which sizes the aft skirt was developed from the relationships in references 1 and 3.

The equation for the aft skirt is:

WSTR4=CSTR4((PI(ADIA/2)^2 + PI (ADIA) TSKIRT))

where:

WSTR4=Aft skirt weight lbs.

PI =constant (3.1415)

ADIA =Diameter of booster, ft.

CSTR4=scaling coefficient

TSKIRT=Aft skirt length, ft.

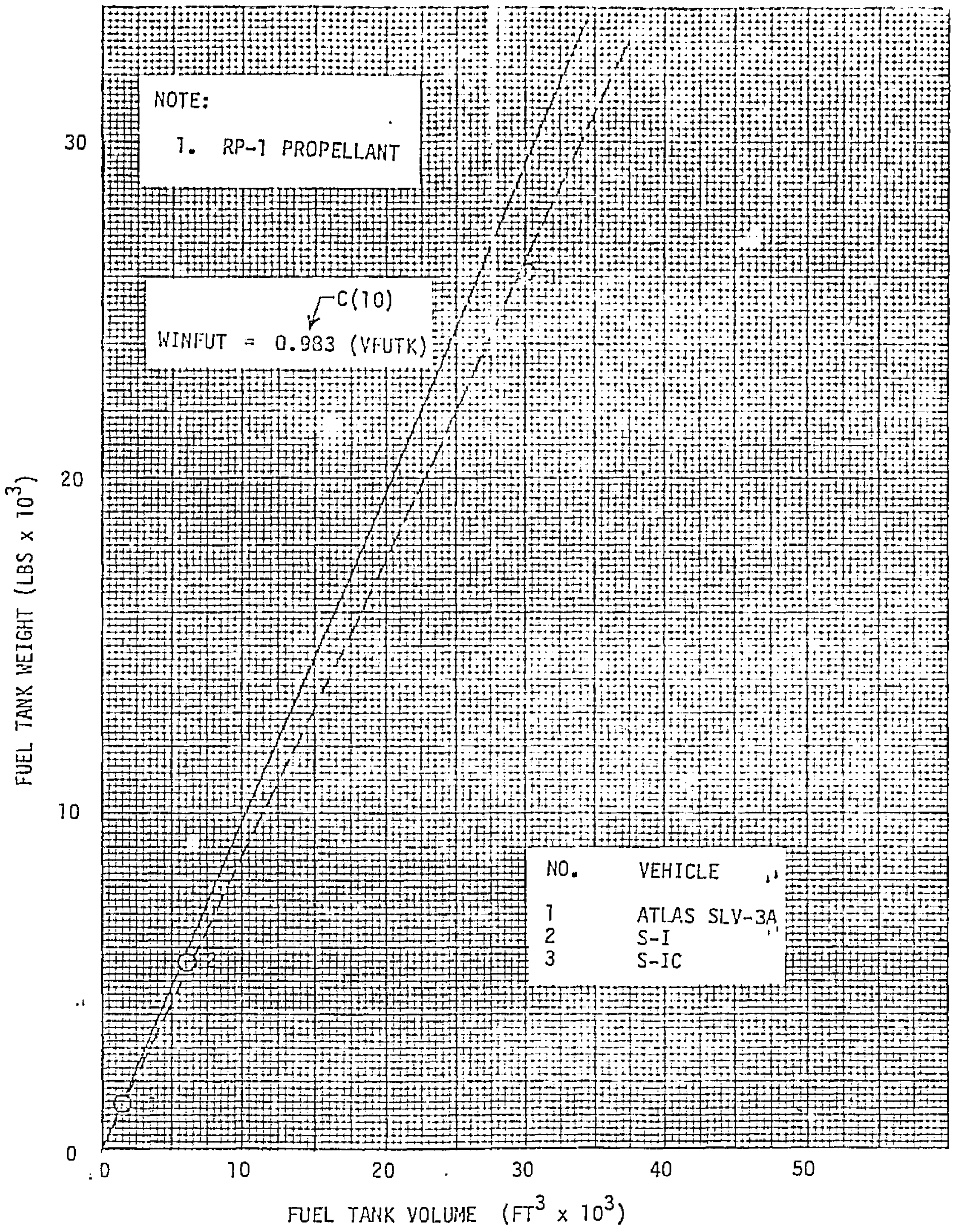


FIGURE VOLUME VERSUS RP-1 TANK WEIGHT.

The value 5.72 lbs/sq ft is representative of Saturn IC Technology (reference 1) to which the aft skirt was scaled.

Thrust Structure. - The weight of the F-1 engine thrust structure is a function of total vaccum thrust and includes the attachment structure and thrust beams. The equation for sizing the thrust structure was obtained from reference 1.

The equation for thrust structure is:

WSTR5=CSTR5*TTOT

where:

WSTR5=Total weight of the thrust structure, lbs.

TTOT =Total vacuum thrust of engines, lbs.

CSTR5=scaling coefficient (.00641).

The value of .00641 is used to scale the thrust sturcture as a function of total stage thrust. This coefficient reflects the Saturn vehicle thrust structure data obtained from reference 1.

Aerodynamic Surfaces

The aerodynamic surfaces for the RP booster consist of three bi-convex type stabilizers located forward of the LOX tank. Their main function is to provide aerodynamic stability during the reentry phase of the RP booster.

Stabilizers. - The weight algorithm for sizing the stabilizers was developed from the aerodynamic sizing equations of reference A constant of 6916. was derived from these relationships. The equation for the stabilizer is:

WFLAP=6916.

where:

WFLAP=Total weight of the stabilizers, lbs.

Thermal Protection System

The thermal protection system (TPS) is assumed to consist of cyrogenic insulation and an ablative heat shield. The insulation is assumed to hold sturctural temperatures to approximately 200°F. The ablative heat shield provides protection from the SSME plume. The ablative material is assumed to cover that portion of the booster which is exposed to the plume (reference 2).

The equation which sums the TPS is:

WTPST=WTPS1+WTPS2

where:

WTPST =TPS Weight, Lbs.

WTPS1 =Insulation Weight, Lbs.

WTPS2=Ablative Heat Shield Weight, Lbs.

Insulation. - The WRR for estimating insulation weight was obtained from references 2 and 3. The equation sizes the insulation as a function of intertank area.

The equation for insulation weight is:

WTPS2=CTPS2(PI)(ARADS)

where:

WTPS2=Insulation Weight, Lbs.

PI =3.14 (Constant)

ARADS=Tank Radius Squared.

CTPS2=scaling coefficient, (1.1)

Ablative Heat Shield. - The equation for sizing the ablative heat shield was obtained from reference 2. The equation sizes the ablative heat shield as a function of total booster length.

The equation for the ablative heat shield is:

CTPS1=CTPS1 (TLEN)

where:

WTPS1=Ablative Heat Shield Weight, Lbs.

TLEN =Total Length of Booster, Ft.

CPTS1=Scaling coefficient, (14.39)

The coefficient 14.39 Lbs./Ft. was obtained from reference 2.

Power Supply/Conversion/Distribution System

The power supply, conversion and distribution system includes the weight items required to generate, convert and distribute electrical power required to operate the various subsystems. The major components represented in this system are the electrical system and the control system.

Electrical System. - The electrical system consists of the generating units, transformers, rectifier units and cabling. The equation for estimating the weight of these systems was obtained from reference 2. The equation sizes the electrical system as a function of booster length and a unit weight distribution coefficient.

The equation for the electrical system is:

WEPS1=CEPS1(TLEN)

where:

WEPS1=Electrical system weight, lbs.

TLEN =Total length of stage, ft.

CEPS1=Scaling coefficient (7.89)

Control System. - The control system consists of the power distribution system and electrical control equipment. The equation for estimating the weight of the control system was developed from the S-IC weight statement. The weight is computed as a function of the electrical system weight.

The equation for the control system is:

WEPS2=CEPS2(WEPS1)

where:

WEPS2=Electrical control system weight, lbs.

WEPS1=Electrical system weight, lbs.

CEPS2=Scaling coefficient (.0168)

Instrumentation System

The instrumentation system provides a weight allocation for the basic instruments required for sensing and readout of flight parameters needed for monitoring a flight profile. These instruments would include telemetry, propellant sensors, measurement equipment, etc.

Instrumentation. - Since the RP booster configuration is similar to Saturn S-IC based technology a constant weight was assumed for the instrumentation. The S-IC weight statement was used as a reference to obtain the value.

The equation for instrumentation is:

WINST=1520

where:

WINST=Instrumentation system weight, lbs.

Propulsion

The booster utilizes the uprated F1 engine. Data on the F1 engine is presented in figures through . In addition to the basic engine weight, other contributing factors to the propulsion system are:

1. Engine Accessories
2. Engine Gimbal system
3. Base heat shield
4. Fuel system
5. Oxidizer system
6. The pressurization and purge system

Engine Weight (Dry).- The equation for dry engine weight was developed from the date in figures through . The equation also accounts for the number of engines employed.

The equation for the calculation of dry engine weight is:

WPROP2=.88(21269.)(ENG)

where:

WPROP2=Total dry engine weight, lbs.

ENG =Number of engines.

If advanced technology engines are used the equation becomes:

WPROP2=5335.(ENG)

Engine Accessories. - The equation for engine accessories was developed from the Saturn S-IC weight statement.

The equation for engine accessories is:

WPROP3=138.8(ENG)

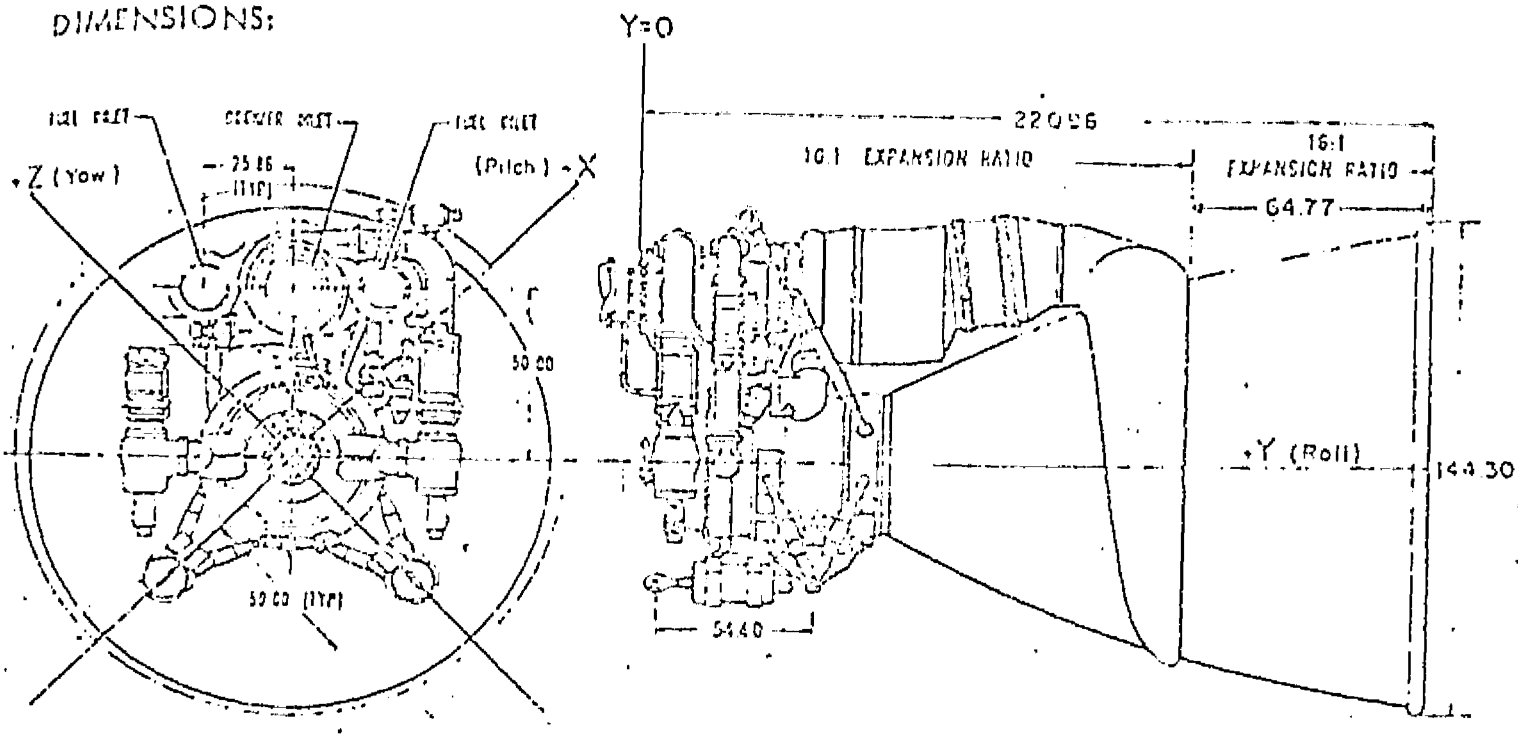
where:

WACC=Total weight of the engine accessories, lbs.

ENG =Number of engines

The coefficient of 138.8 lbs/eng was obtained from the S-IC weight statement.

DIMENSIONS:



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ENGINE CHARACTERISTICS:

- Engines F-2090 and Subsequent

PARAMETER	UNITS	NOMINAL VALUE	TOLERANCE, %
Engine Thrust			
Sea Level	$lb \times 10^{-6}$	1.522	± 1.5
Vacuum	$lb \times 10^{-6}$	1.748	± 1.5
Specific Impulse			
Sea Level	$lb_f\text{-sec}/lb_m$	265.2	± .9
Vacuum	$lb_f\text{-sec}/lb_m$	304.4	
Propellant Density			
Liquid Oxygen	lb/ft^3	71.38	
RP-1	lb/ft^3	50.45	
Propellant Mixture Ratio		2.27	± 2

FIGURE F-1 ENGINE CHARACTERISTICS.

PARAMETER	UNITS	NOMINAL VALUE	TOLERANCE,%
Standard Pump Inlet Press			
Oxidizer	PSIA	65	
Fuel	PSIA	45	
Injector End Chamber Press	PSIA	1126	
Flow Rates (Engine)			
Oxidizer	LB/SEC	3984	
Fuel	LB/SEC	1753	
Engine Weight			
Wet	LBS	20,865 23,253	
Dry	LBS	18,612 ~1073	
BURNOUT	LBS	20,865	
Throat Area	SQ. IN.	961.0	
Exit Area	SQ. IN.	15400	
Expansion Ratio		16:1	

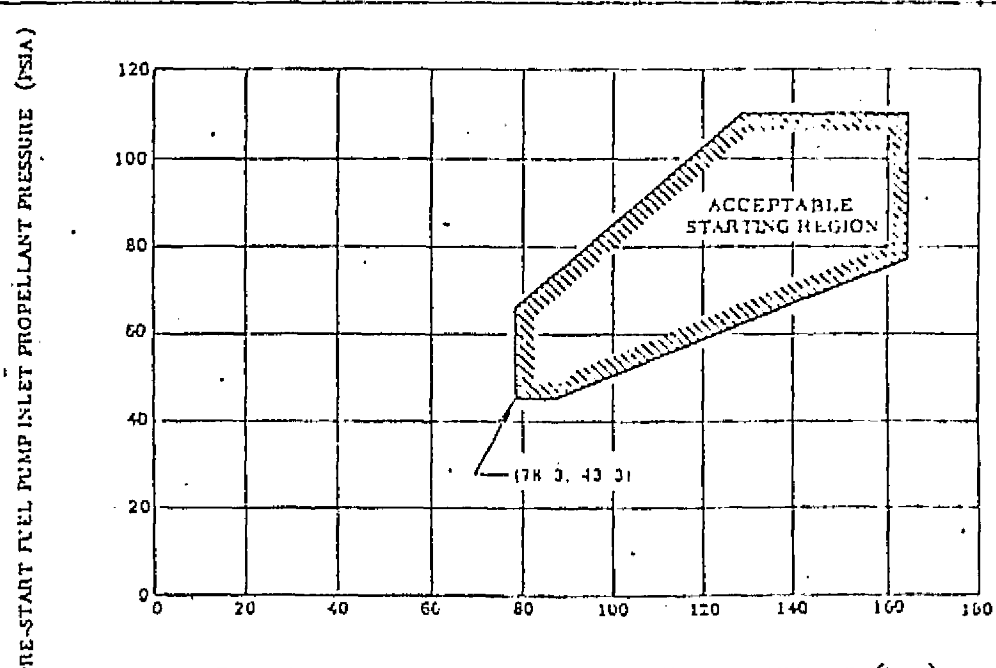


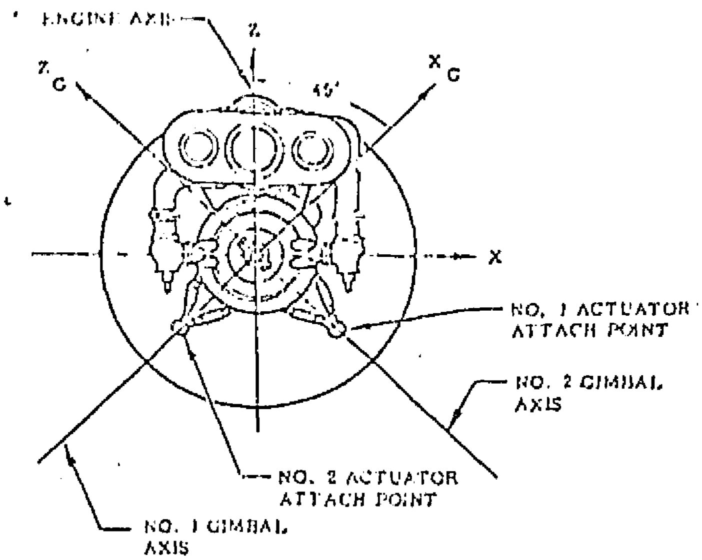
FIGURE ——F-1 ENGINE CHARACTERISTICS.

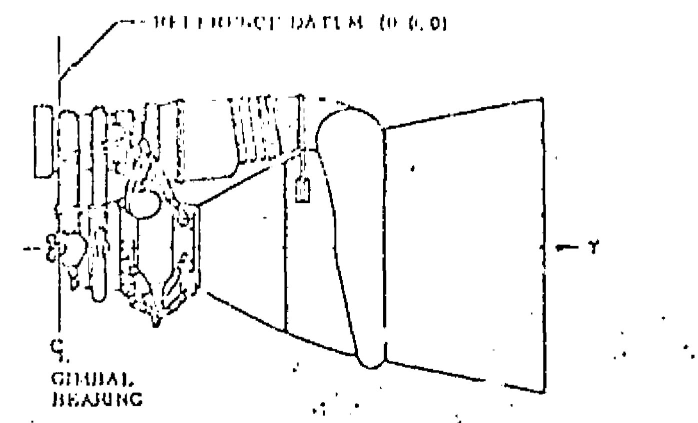
MASS PROPERTIES:

- Engines F-2090 and Subsequent

ITEM	DESCRIPTION	WEIGHT, LBS.
1 + 2	Rocket Engine--Wet	20,865
1 + 3	Rocket Engine -- Burnout	20,441
1	Rocket Engine -- Dry	18,612
	Thrust Chamber (Including skirt, 1,621 lb)	8,507
	Gimbal Bearing	467
	Turbopump	3,151
	Turbopump Mount (including Provisions on T/C, 286 lb)	342
	Oxidizer System	653
	Fuel System	642
	Purge System	38
	Electrical System	85
	Gimbal Supply System	181
	Gas Generator System	340
	Exhaust System (Including T/C exhaust manifold, 826 lb)	994
	Flight Instrumentation	145
	Ignition System	47
	Interface Installation	542
	Pressurization System (Including heat exchanger, 823 lb)	1,029
	Hydraulic Control System	193
	Thermal Insulation--Permanent	72
	Thermal Insulation Set (TIS)	1,182
2	Rocket Engine Fluids (System Full)	2,253
3	Rocket Engine Fluids (Burnout)	1,879

FIGURE F-1 ENGINE CHARACTERISTICS.





NOTE
ARROW INDICATES POSITIVE (+) DEFLECTION; Y, X, Z = ENGINE AXES. Y, X_G, Z_G = GIMBAL AXES

Coordinate Axis Diagram

Description	Weight (Lb)	Center of Gravity (Inches)			Axis System Orientation	Origin of Axes (Inches)			Moments of Inertia (Slug Ft^2)		
		$\bar{Y}$ (+)	$\bar{X}$ (+)	$\bar{Z}$ (+)		Y (+)	X (+)	Z (+)	I_y	I_x	I_z
Rocket Engine-Dry	18,612	56.4	11.6	11.7	Gimbal	56.4	11.6	11.7	6,850	17,650	17,675
Rocket Engine-Wet	20,865	54.5	12.0	11.9	Gimbal	54.4	12.0	11.9	7,605	19,007	19,090
Wet Gimbaled Mass.	20,670	55.1	0.1	17.1	Engine	0.0	0.0	0.0	8,887	34,680	31,580
Wet Gimbaled Mass.	20,670	55.1	12.1	12.0	Gimbal	0.0	0.0	0.0	8,887	33,084	33,176

FIGURE F-1 ENGINE CHARACTERISTICS.

Engine Gimbal System. - The equation for the estimation of the F1 engine gimbal system was developed from the S-IC weight statement.

The equation for the gimbal system is:

WPROP4=1761.(ENG)

where:

WPROP4=Weight of the engine gimbal system, lbs.

ENG =Number of engines.

If advanced technolgy engines are used the equation becomes:

WPROP4=.001420(TTOT)

where:

TTOT=total thrust, lbs.

The equation for the base heat shield is:

$$WPROP5=4.(ADIA)^2$$

where:

WPROP5=Base Heat Shield Weight, lbs.

ADIA=Diameter of Base, FT.

Fuel System. - The fuel system includes the weight of those items necessary to deliver the fuel from the vehicle storage tanks to the engine pump inlets, tank venting and propellant dumping requirements. The weight of these systems is highly dependent on the vehicle tank and propulsion system layout and the ease of ducting required to perform the propellant transfer function. The algorithm for the estimation of fuel system weight was developed from the S-IC weight statement.

The equation for the fuel system is:

WPROP6=2796.2(ENG)

where:

WPROP6=Fuel System Weight, Lbs.

ENG =Number of Engines.

Oxidizer System. - THe oxidizer system includes those items needed to transfer oxidizer from the vehicle LOX tank to the engine system and the components required to vent or dump the LOX tank. The algorithm for the weight estimation of the oxidizer system was developed from the S-IC weight statement.

The equation for the oxidizer system is:

WPROP7=(2796.2(ENG))+(.0113537(WDOTOX) (TLRP)

where:

WPROP7=Weight of Oxidizer System, Lbs.

ENG =Number of Engines.

TLRP=Length of RP Tank, Ft.

WDOTOX=WDOT(MRR)/MRR+1.

WDOT =Propellant Flow Rate, Lbs./Sec.

MRR =Mixture Ratio.

Separation and Recovery System

The separation and recovery system is assumed to consist of the following components:

1. Separated System
2. Chute System (Main and Drogue)
3. Floation System
4. Recovery System
5. Fittings and Supports
6. Retro System (100 F/S Del V)
7. Reentry Heat Shield

The equation which sums these components is:

WSEPT=WSEP1+WSEP2+WSEP3+WSEP4+WSEP5+WSEP6+WSEP7

where:

WSEPT=Total Weight of Separation and Recovery System, Lbs.

WSEP1=Booster Separation System, Lbs.

WSEP2=Chute System Weight, Lbs.

WSEP3=Floation System, Lbs.

WSEP4=Recovery Aids, Lbs.

WSEP5=Fittings and Supports, Lbs.

WSEP6=Retro System, Lbs.

WSEP7=Reentry Heat Shield, Lbs.

Booster Separation System. - The separation system weight includes the system and attachments that are used for separating the booster from the ET. This weight includes the separation system backup structure required to react the loads as well as the fittings and structure that attaches the two stages. The WERl was developed from the S-IC weight statement.

The equation for the separation system is:

WSEP1=24.(PI) (ADIA)

where:

WSEP1=Separation System Weight, Lbs.

PI =3.1415 (Constant)

ADIA=Stage Diameter, Ft.

The coefficient 24. Lbs./Ft. was developed from the S-IC weight statement.

Chute System (Main and Drogue). - The chute system consists of the main, drogue and pilot chutes, cannisters and deployment mechanisms. The equation for estimating the weight of the chute system was developed by scaling to the solid rocket booster (SRB) system (reference 2).

The equation for the chute system is:

WSEP2=.029742(TEMP)

where:

WSEP2=Chute System Weight, Lbs.

TEMP =Inert Weight of Booster without Separation System, Lbs.

Floatation System. - The equation for the estimation of floatation system weight was developed by scaling to the SRB floatation system weight (reference 2).

The equation for the floatation system is:

WSEP3=.000538(TEMP)

where:

WSEP3= Floatation System Weight, Lbs.

TEMP = Inert Weight of the Booster without the Separation System, Lbs.

Recovery Aids.- The equation for the estimation of the recovery aid system was developed by scaling to the SRB recovery aid system (reference 2).

The equation for the recovery system is:

WSEP4=.0005311(TEMP)

where:

WSEP4=Recovery System Weight, Lbs.

TEMP = Inert Weight of the Booster without the Separation System.

Fittings and Supports. - The equation for estimating the weights of the fittings and supports associated with the separation system was developed by scaling to the SRB system (reference 2).

The equation for estimation of the fittings and support weight is:

WSEP5=.001024(TEMP)

where:

WSEP5=Fittings and Supports Weight, lbs.

TEMP =Inert Weight of Booster without the Separation and Recovery System, lbs.

Retro System. - The retro system was sized for an 100 ft./sec. delta velocity requirement. The equation for estimation of the solid rocket retro system was obtained from reference 2. The weight is assumed to include the propellant and casings.

The equation for the retro system is:

WSEP6=1.365 (TEMP(DELX)/(1.-(.3743) (DELX))

where:

WSEP6=Retro System Weight, lbs.

TEMP =Inert Weight of Booster without the Separation and Recovery System, lbs.

DELX $=e^{(RETDV/(G(RETISP))-1.)}$

RETDV=Delta Velocity Requirement, Ft./Sec.

G =32.174

RETISP=Specific Impulse, Sec.

Reentry Heat Shield. - The equation for the determination of the reentry heat shield weight was obtained from reference 2.

The equation for the reentry heat shield is:

WSEP7=5.(PI) (ARADS)+600

where:

WSEP7=Reentry System Weight, lbs.

PI =3.14

ARADS=Radius of Booster Squared.

Stage Dry Weight

The equation for the RP stage dry weight sums all the dry weight systems.

The equation for dry weight is:

WDRY=WBSTRT+WSTAB+WTPS+WEST+WINST+WESYS+WSEPT

Where:

WDRY =Total dry weight of the stage, lbs.

WBSTRT=Total structural weight of the system, lbs,

WSTAB =Total weight of the aerodynamic surfaces, lbs.

WTPS =Total weight of the thermal protection system, lbs.

WEST =Total weight of the electrical system, lbs.

WINST =Total weight of the instrumentation system, lbs.

WESYS =Total weight of the engine system, lbs.

WSEPT =Total weight of the separation system, lbs.

Design Reserve Contingency

The design reserve contingency is computed as a function of stage dry weight. The contingency weight is included to account for the uncertainties in the basic weight estimates.

The equation for contingency is:

WCONT=CRES(WDRY)

where:

WCONT=Design reserve contingency, lbs.

CRES =Contingency coefficient.

WDRY =Total dry weight of the stage,lbs.

Empty Weight

The empty weight of the stage is computed bu summing the dry weight of the stage and the contingency.

The equation for empty weight is:

WEMPTY=WDRY+WCONT

where:

WEMPTY=Empty weight of the stage, lbs.

WDRY =Total dry weight of the stage, lbs.

WCONT =Design reserve contingency.

Propellant Residuals

The contributing factors to propellant residuals assumed for this study are:

1. Fuel Bias
2. Trapped LOX Tank Gases
3. Trapped RP-1 Tank Gases
4. Trapped Frost
5. Trapped RP
6. Trapped LOX

Fuel Bias. - A constant of 1800 pounds was assumed for a fuel bias (reference 2.)

Trapped LOX Tank Gases. - The equation for the estimation of trapped LOX tank gases was developed from references 1 and 2. The computed weight includes liquid as well as gas residuals remaining in the LOX tank and lines.

The equation for the estimation of LOX tank gas residuals is:

WRES2 =.151619 (VOXT)

Where:

WRES2 =LOX Tank Gas Residuals, lbs.

VOXT =Total Volume of the LOX Tank, Cu. Ft.

Trapped Fuel Tank Gases. - The equation for the estimation of trapped fuel tank gases was developed from references 1 and 2. The computed weight includes liquid as well as gas residuals remaining in the fuel tank and lines.

The equation for the estimation of RP tank gas residuals is:

WRES3=.21514 (VRPT)

where:

WRES3=RP Tank Gas Residuals, lbs.

VRPT =Total Volume of the fuel tank, Cu. Ft.

Frost Trapped. - The frost which is trapped in the tank system is included as a residual because of its potential weight contribution to the system. The equation for the estimation of the amount of frost which is trapped was developed from the Saturn S-IC weight statement.

The equation for trapped frost is:

WRES4=.0104416(TVOL)

where:

WRES4=Weight of trapped frost, lbs.

TVOL =Total volume of the LOX and fuel tank.

Trapped Fuel. - The trapped fuel is assumed to be that fuel which is trapped in the fuel tank, feed lines and F1 engine. The algorithm which estimates the trapped fuel weight was developed from references 1 and 3.

The equation for trapped fuel is:

WRES5=.01691(WFL)

where:

WRES5 =Total weight of trapped fuel, lbs.

WFL =Total weight of the full fuel, lbs.

The coefficient .01691 was developed from the Saturn S-IC weight statement.

Trapped Oxidizer. - The trapped oxidizer is assumed to be the amount of oxidizer which is trapped in the LOX tank, LOX feed lines and engine. The algorithm which estimates the amount of trapped oxidizer was developed from references 1 and 3.

The equation for trapped oxidizer is:

WRES6=.01039(WOX)

where:

WRES6=Total weight of trapped oxidizer, lbs.

WOX =Total weight of LOX.

The coefficient .01039 was developed from Saturn S-IC data.

In-Flight Losses

The inflight losses include the amount of LOX and fuel propellant lost (vented) during the fuel booster ascent.

Fuel Losses. - The equation for estimating fuel losses was developed from reference

The equation for estimating fuel losses is:

WLOS1=.0027198(WFL)

where:

WLOS1=Total RP-1 loss, lbs.

WFL =Total weight of fuel, lbs.

LOX Losses. - The equation for estimating LOX losses was developed from reference

The equation for estimating LOX loss is:

WLOS2=.0012812(WOX)

where:

WLOS2=Total LOX loss, lbs.

WOX =Total weight of LOX propellant, lbs.

Main Propellants

The main propellants are computed from a total propellant requirement and adjusted for mixture ratio.

RP Propellant. - The equation for RP propellant is:

WFL=WPROP/(MRR+1.)

where:

WFL =Total weight of RP1 main propellant, lbs.

WPROP=Total propellant requirement.

MRR =Mixture Ratio.

LOX Propellants. - The equation for LOX propellant is:

WOX=MRR(WPROP)/(MRR+1.)

where:

WOX =Total weight of LOX propellant, lbs.

WPROP=Total propellant requirement, lbs.

MRR =Mixture ratio.

Stage BLOW

The stage BLOW equation sums the weights of the system components and propellants.

The equation for the stage BLOW is:

WBLOW=WEMPTY+WFPR+WLOST+WREST+WPROP

where:

WBLOW =Stage BLOW, lbs.

WEMPTY=Stage Empty Weight, lbs.

WFPR =Flight Performance Reserve, lbs.

WLOST =Inflight Losses, lbs.

WPROP =Total Propellant Requirement, lbs.

WREST =Propellant Residuals, lbs.